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PAPER/ÉTUDE
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CURRENT RESEARCH, PART F
FRONTIER GEOSCIENCE PROGRAM

CORDILLERAN AND OFFSHORE BASINS, BRITISH COLUMBIA

RECHERCHES EN COURS, PARTIE F
PROGRAMME GÉOSCIENTIFIQUE DES RÉGIONS PIONNIÈRES

BASSINS DE LA CORDILLÈRE ET EXTRACÔTIERS, COLOMBIE-BRITANNIQUE

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BASSINS DE LA CORDILLÈRE ET EXTRACÔTIERS, COLOMBIE-BRITANNIQUE

1990

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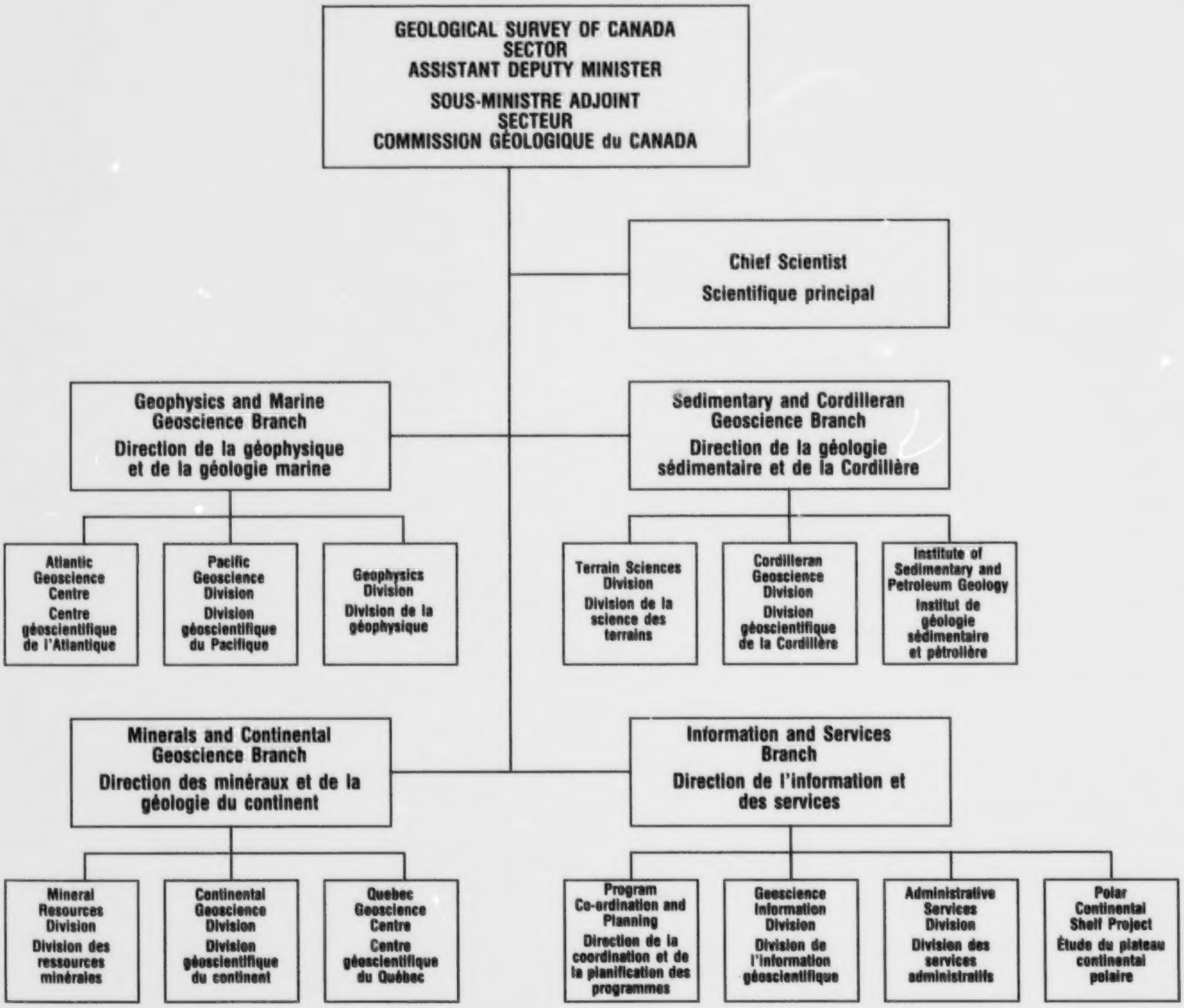
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Field activities of the Queen Charlotte Islands Frontier Geoscience Program, 1989[1]

James W. Haggart
Cordilleran Division, Vancouver

Haggart, J.W., Field activities of the Queen Charlotte Islands Frontier Geoscience Program, 1989; in Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 1-3, 1990.

INTRODUCTION

The Geological Survey of Canada's Queen Charlotte Islands Frontier Geoscience Program (FGP) entered its third field season in 1989. Although the total number of personnel participating in field studies has declined slightly over the past several years, exciting geological discoveries continue to be made. New stratigraphic units were identified in 1989 and new fossil floras and faunas were collected. Structural studies revealed that some areas of the islands not previously examined under FGP are characterized by structural trends of a different nature than seen in the better-studied central islands region. Analysis of Pleistocene sediments suggests that glaciation during that time was extensive in the Queen Charlotte Islands and Hecate Strait region.

Public interest in our program in the Queen Charlotte Islands continues to be strong. Members of the staff of the Cordilleran Division were invited to participate in a public meeting in Masset, British Columbia in the spring, and several radio interviews with local media representatives were given during the field season. In discussing our program, its mandate and goals, the most important theme repeated at all these public functions is that the Frontier Geoscience Program has been implemented to provide a state-of-the-art geoscience database for the area, available to all Canadians.

The new data and observations discussed in the following papers have significantly expanded or revised interpretations in their respective disciplines and reflect a continually improving understanding of the geological evolution of the Queen Charlotte Islands. A few highlights from these papers are discussed in the following paragraphs.

Travaux sur le terrain du programme géoscientifique des régions pionnières des îles de la Reine Charlotte, 1989[1]

James W. Haggart
Division de la Cordillère, Vancouver

Haggart, J.W., Travaux sur le terrain du Programme géoscientifique des régions pionnières des îles de la Reine-Charlotte, 1989, dans Recherches en cours, Partie F, Commission géologique du Canada, Étude 90-1F, p. 1-3, 1990.

INTRODUCTION

Le programme géoscientifique des régions pionnières des îles de la Reine-Charlotte de la Commission géologique du Canada a commencé sa troisième campagne de terrains en 1989. Bien que le nombre total de personnes qui participent à des études sur le terrain ait baissé légèrement au cours des dernières années, on continue à faire des découvertes géologiques passionnantes. En 1989, on a déterminé de nouvelles unités stratigraphiques et prélevé de nouvelles flores et faunes fossiles. Des études structurales révèlent que certaines régions des îles non étudiées auparavant dans le cadre du PGRP sont caractérisées par des tendances structurales d'une nature différente que celles qu'on a vues dans les îles centrales mieux étudiées. L'analyse des sédiments pléistocènes laisse supposer que la glaciation au cours de cette période était importante dans les îles de la Reine-Charlotte et du détroit d'Hécate.

L'intérêt que témoigne le public à l'égard de notre programme dans les îles de la Reine-Charlotte continue à être important. Les membres du personnel de la Division de la Cordillère ont été invités à une assemblée publique à Masset au printemps, et plusieurs interviews par radio avec des représentants locaux des médias ont été donnés au cours de la campagne de terrain. En examinant le mandat et les objectifs de notre programme, le thème le plus important répété à toutes les fonctions publiques est que le programme géoscientifique des régions pionnières avait été mis en œuvre pour fournir une base de données géoscientifiques d'avant-garde pour la région, dont peuvent disposer tous les Canadiens.

---

[1] Contribution to Frontier Geoscience Program

MAPPING

The geological mapping program continued to expand its coverage of the islands (Fig. 1). Detailed fieldwork by J. Hesthammer and J. Indrelid in central Graham Island has now linked up earlier map coverage of the northern two-thirds of Graham Island, dominated by the Masset Formation volcanics, with the Honna River and Skidegate Inlet region in the south, characterized by late Mesozoic sedimentary strata. Hesthammer and Indrelid, working with C. Gamba and J. Haggart, also undertook a reconnaissance study of the alpine region around Mount Stapleton and Yakoun Lake, noting that the zone of extensive deformation characteristic of the Cumshewa Inlet-Skidegate Inlet region can be traced into that area as well.

Further work by P. Lewis has served to delimit the timing of late Mesozoic and Tertiary deformation events while S. Taite, mapping in the Sewell Inlet-Tasu Sound area, has identified a predominant north-south structural trend which has not previously been recognized elsewhere in the islands. Both these studies are important contributions to the study of the deformational history of the Queen Charlotte Islands.

A new stratigraphic unit was identified; its Paleogene age was established with palynological identifications by J. White. Consisting of black, nonmarine, exceptionally rusty-

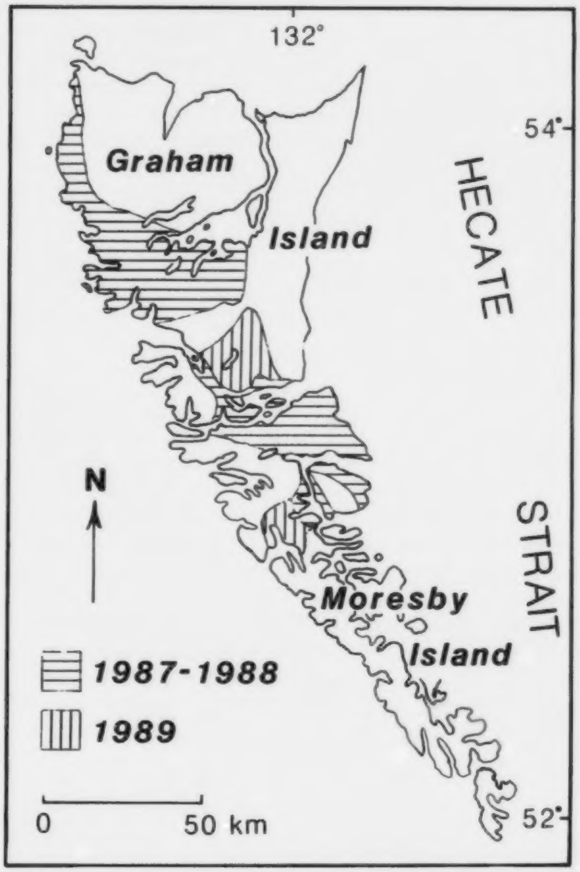

Figure 1. The Queen Charlotte Islands of British Columbia showing the geological mapping coverage to date.

Les nouvelles données et observations étudiées dans les 16 articles qui suivent la présente introduction ont considérablement étendu ou modifié les interprétations dans les disciplines en cause et reflètent une compréhension qui s'améliore continuellement de l'évolution géologique des îles de la Reine-Charlotte. Nous examinons dans les paragraphes suivants quelques faits saillants de ces articles.

CARTOGRAPHIE

Le programme de levés géologiques continue à couvrir les îles (voir figure 1). Des travaux sur le terrain détaillés effectués par J. Hesthammer et J. Indrelid dans la partie centrale de l'île Graham ont maintenant lié la première couverture des deux tiers nord de l'île Graham, où prédominent les roches volcaniques de la formation de Masset, avec la région de la rivière Honna et de l'inlet Skidegate au sud, caractérisée par des couches sédimentaires du Mésozoïque supérieur. Hesthammer et Indrelid, travaillant avec C. Gamba et J. Haggart, ont également entrepris une étude de reconnaissance de la région alpine autour du mont Stapleton et du lac Yakoun, faisant remarquer que la zone à déformation intense, caractéristique de la région de l'inlet Cumshewa — inlet Skidegate, peut être également suivie dans cette région.

D'autres travaux effectués par P. Lewis ont servi à délimiter l'âge des déformations du Mésozoïque supérieur et du Tertiaire, alors que S. Taite au cours du levé géologique de la région de l'inlet Sewell-baie Tasu, a déterminé une direction structurale nord-sud prédominante qu'on avait pas identifiée auparavant, ailleurs dans les îles. Ces deux études ont contribué énormément à l'étude de l'histoire des déformations des îles de la Reine-Charlotte.

Une nouvelle unité stratigraphique a été déterminée; J. White a établi son âge paléogène au moyen d'identifications palynologiques. L'unité, constituée de shales et de grès non marins, noirs, accompagnée d'horizons locaux de charbon et qui exceptionnellement s'altèrent et deviennent rouille, a été reconnue à plusieurs endroits dans la partie sud de l'île Graham.

BIOSTRATIGRAPHIE

Des études biostratigraphiques du Jurassique continuent à dominer les recherches paléontologiques. H.W. Tipper, P. Smith, G.K. Jacobs, E.S. Carter et J. Palfy, aidés par M.J. Orchard, ont étudié la limite du Trias et du Jurassique dans les îles de la Reine-Charlotte; ils se sont en outre penchés sur des problèmes biostratigraphiques spécifiques du Jurassique. Le groupe de travail pour le Jurassique dans les îles de la Reine-Charlotte utilise des radiolaires, des ammonites, des bivalves et des conodontes pour produire des zonations biostratigraphiques intégrées capables de servir comme normes en Amérique du Nord. De plus, Jakobs et Carter, travaillant avec B. Galbrun, ont effectué des études magnétostratigraphiques de certaines portions de sections triasiques et jurassiques en vue d'améliorer des collaborations régionales et internationales.

Figure 1. îles de la Reine-Charlotte de la Colombie-Britannique montrant la couverture géologique à ce jour.

weathering shale and sandstone with local coal horizons, the unit has been recognized at several localities in the southern Graham Island region.

BIOSTRATIGRAPHY

Jurassic biostratigraphic studies continue to dominate paleontological investigations. Work by H.W. Tipper, P. Smith, G.K. Jakobs, E.S. Carter, and J. Pálfy, supported by M.J. Orchard, has investigated the Triassic-Jurassic boundary in the Queen Charlotte Islands, as well as focusing on specific biostratigraphic problems of the Jurassic. The Jurassic "working group" in the Queen Charlotte Islands is using radiolaria, ammonites, bivalves, and conodonts to produce integrated biostratigraphic zonations capable of serving as North American standards. In addition, Jakobs and Carter, working with B. Galbrun, have undertaken magnetostratigraphic studies of select portions of the Triassic and Jurassic sections to improve regional and international correlations.

Lower Cretaceous mollusc biostratigraphy has been pursued by J. Haggart. Faunas have been identified from strata of the Longarm Formation in the South Moresby part of the Queen Charlotte Islands which are similar to faunas previously studied from the northern portion of the archipelago. Thus, correlation of strata of this age is greatly improved.

Other paleontological work has been undertaken by R.T. Patterson, studying late Quaternary benthic foraminifera. The study of these faunas is being used by Patterson to decipher the paleoenvironments of the shelf at that time. A further aspect of this study is an improved understanding of the associated sea level changes, an important component of understanding the potential hazards to offshore exploration in the area.

SEDIMENTOLOGY

The dramatic progress in Jurassic biostratigraphic studies in the Queen Charlotte Islands has highlighted the need for detailed sedimentological examination of this part of the Mesozoic succession. No other system in the Queen Charlotte Islands includes the diversity of complexly related sedimentary and volcanic lithologies and facies seen in the Jurassic.

For the Lower Cretaceous, J. Haggart and C. Gamba have expanded an analysis of the stratigraphy and sedimentology of the Longarm Formation. Their analysis indicates that the formation is a widespread, tectonically quiescent deposit reflecting a single, shallow-marine transgressive episode.

The younger Cretaceous Queen Charlotte Group, focus of a flurry of investigations over the last several years, continues to attract attention. Further study of the Honna Formation conglomerates undertaken by C. Gamba and colleagues invoked a new interpretation for the origin of their regionally discordant paleocurrent trends.

J. Haggart a poursuivi la biostratigraphie des mollusques du Crétacé inférieur. Il a déterminé des faunes à partir des couches de la formation de Longarm dans la partie sud de Moresby des îles de la Reine-Charlotte ; ces faunes sont très similaires aux faunes étudiées antérieurement dans la partie nord de l'archipel. Ainsi, la corrélation des couches de cet âge est considérablement améliorée.

R.T. Patterson a effectué d'autres travaux paléontologiques en étudiant des foraminifères benthiques du Quaternaire supérieur. Patterson utilise l'étude de ces faunes pour débrouiller les paléo-environnements de la plate-forme continentale à cette époque. Un autre aspect de cette étude est une meilleure compréhension des changements du niveau de la mer associés, importante composante pour comprendre les risques possibles de l'exploration en mer dans cette région.

SÉDIMENTOLOGIE

Les progrès éclatants des études biostratigraphiques du Jurassique dans les îles de la Reine-Charlotte ont fait ressortir le besoin d'un examen sédimentologique détaillé de cette partie de la succession mésozoïque. Aucun autre système dans les îles de la Reine-Charlotte comprend la diversité des lithologies et des faciès sédimentaires et volcaniques, liées d'une façon complexe, rencontrées dans le Jurassique.

Au Crétacé inférieur, J. Haggart et C. Gamba ont poussé une analyse de la stratigraphie et de la sédimentologie de la formation de Longarm. Cette analyse indique que la formation représente un dépôt étendu, à tectonique tranquille, reflétant une seule épisode transgressive de mer peu profonde.

Le groupe le plus jeune de Queen Charlotte du Crétacé, siège d'une soudaine poussée de recherches au cours des dernières années, continue à attirer l'attention. D'autres études effectuées sur les conglomérats de la formation de Honna par C. Gamba appellent une nouvelle interprétation quant à l'origine de leur direction des paléocourants discordants régionalement.

Des analyses géochimiques de la formation de Skonun du Tertiaire, effectuées par M. Bustin, D. Vellutini et F. Goodarzi, laissent penser que cette cible réservoir principale se trouvant dans le bassin de la Reine-Charlotte peut avoir localement des possibilités modérées de roches mères.

Enfin, T. Fuller, qui a travaillé sur des sédiments pléistocènes situés sur la côte nord-est des îles de la Reine-Charlotte, a déterminé des fabriques et des compositions de till qui laissent supposer une dérivation à partir d'une source de la terre ferme. Fuller accepte que la glace des glaciers dans les îles ont fusionné avec l'inlandsis de la Cordillère, couvrant le détroit de Hécate au cours d'une partie du Pléistocène.

Geochemical analyses of the Tertiary Skonun Formation, undertaken by M. Bustin, D. Vellutini, and F. Goodarzi, have suggested that this principal reservoir target in the Queen Charlotte Basin may locally have moderate source rock potential.

Finally, T. Fuller, working in Pleistocene sediments on the northeast coast of the Queen Charlotte Islands, has determined till fabrics and compositions that suggest derivation from a mainland source. Fuller postulates that glacial ice in the islands merged with the Cordilleran Ice Sheet, covering Hecate Strait during part of the Pleistocene.

This sampling of the activities presently being funded by the Geological Survey of Canada's Frontier Geoscience Program in the Queen Charlotte Islands reflects the research interests of a diverse group of investigators. It is clear that the exciting discoveries being made in a wide variety of geological disciplines reflect a wealth of geoscience information still to be gleaned from this important region of Canada's Pacific coast.

Cet échantillonnage des activités financées actuellement par le Programme géoscientifique des régions pionnières de la Commission géologique du Canada dans les îles de la Reine-Charlotte reflète l'intérêt de recherche d'un groupe divers de chercheurs. Il est évident que les découvertes passionnantes faites dans une grande variété de disciplines géologiques reflètent une abondance de données géoscientifiques devant être glanées à partir de cette région importante de la Côte Pacifique du Canada.

Stratigraphy and structures of Cretaceous units, central Graham Island, Queen Charlotte Islands, British Columbia[1]

Jarand Indrelid[2]
Cordilleran Division, Vancouver

Indrelid, J., Stratigraphy and structures of Cretaceous units, central Graham Island, Queen Charlotte Islands, British Columbia; in Current Research, Part F, Geological Survey of Canada, Paper 90-1F p. 5-10, 1990

Abstract

Cretaceous rocks of central Graham Island are composed of Hauterivian to Coniacian mudstone, sandstone, and conglomerates of the Longarm, Haida, Skidegate, and Honna formations. Post-Late Cretaceous compression is recorded as gentle to close, northwest-trending folds which locally overturn bedding. From regional distribution of Cretaceous strata, large-scale northwest-trending extensional faults are inferred. The predominant structures in outcrop are small-scale strike-slip Tertiary faults, which reflect the latest period of deformation in the area.

Résumé

Les roches crétacées de la partie centrale de l'île Graham sont constituées de mudstones, de grès et de conglomérats datant de l'Hauterivien au Coniacien des formations de Longarm, de Haida, de Skidegate et de Honna. La compression postérieure au Crétacé supérieur se manifeste sous forme de plis doux à serrés, de direction nord-ouest, qui par endroits montrent une stratification renversée. La répartition régionale des couches du Crétacé permet de déduire la présence de failles d'extension, à grande échelle, de direction nord-ouest. Les structures qui prédominent dans les affleurements sont des failles du Tertiaire à rejet horizontal, à petite échelle, qui reflètent la dernière période de déformation dans la région.

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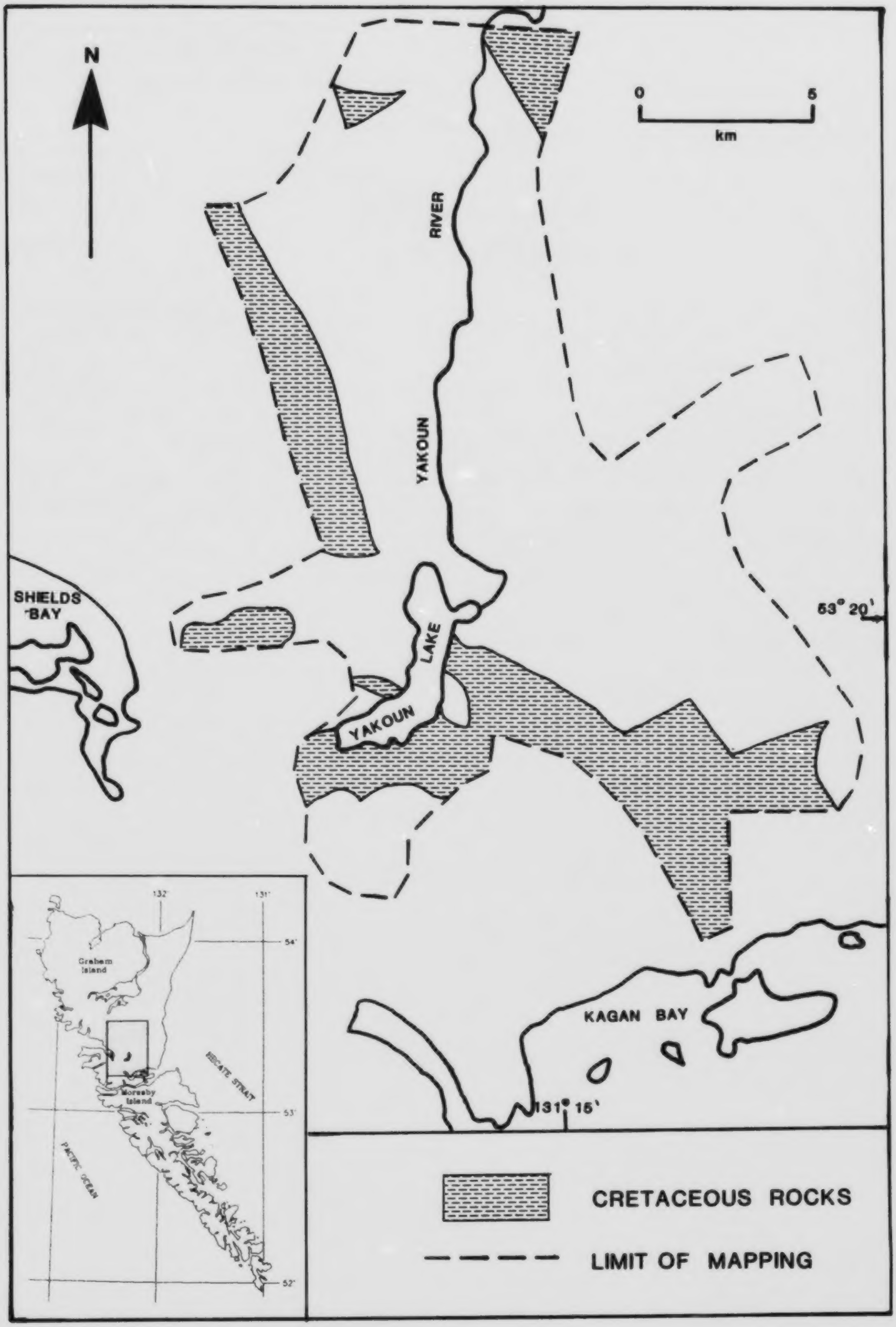
[1] Contribution to Frontier Geoscience Program

[2] Department of Geological Sciences, University of British Columbia, 6339 Stores Road, Vancouver, British Columbia V6T 2B4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Graham Island
Moresby Island
HECATE STRAIT
53°
PACIFIC OCEAN
52°
CRETACEOUS ROCKS
LIMIT OF MAPPING

Figure 1. Distribution of Cretaceous rocks in central Graham Island, Queen Charlotte Islands.

INTRODUCTION

As part of the Frontier Geoscience Project (FGP) of the Geological Survey of Canada and as an MSc project, a detailed study of central Graham Island began in the summer of 1988. Hesthammer et al., (1989) provided a preliminary report and Indrelid et al., (1990) focused on the structures in the area. During the 1989 field season, the extent of the mapped area was increased, and structural data were collected.

This report emphasizes the lithologies and structures of the Cretaceous units in the mapped area (Fig. 1). Jurassic rocks are treated in a companion report by Hesthammer (1990).

STRATIGRAPHY

The Cretaceous stratigraphy of the area (Fig. 2) has traditionally been divided into the Lower Cretaceous (Valanginian to Barremian) Longarm Formation unconformably overlain by the mid-Cretaceous (Albian to Coniacian) Queen Charlotte Group. The Queen Charlotte Group consists of the Haida, Skidegate, and Honna formations (Sutherland Brown, 1968; Cameron and Hamilton, 1988).

Detailed work in connection with the FGP has contributed greatly to the revised understanding of the Cretaceous stratigraphy of the Queen Charlotte Islands (Fogarassy, 1989; Haggart, 1989; Haggart et al., 1989). It is now generally believed that the Haida and Skidegate formations are largely time equivalent and were deposited in a transgressive regime. The Honna Formation represents submarine fan deposits that interfinger with parts of the other formations of the Queen Charlotte Group.

Cretaceous sandstones

Mapping in the central Graham Island area was complicated by the difficulty in distinguishing between sandstones of the Longarm and Haida formations. In some localities the distinction was based entirely on classification of megafossils. Therefore it is convenient to describe the lithologies of the sandstones of Hauterivian to Albian age as one unit. J.W. Haggart (personal communication, 1990) has reported finds of Aptian to Albian megafossils in the sandstone farther south on the islands, closing the earlier inferred time gap between the Longarm and Haida formations. Continuous deposition through the Longarm and Haida formations is likely (Haggart, 1990).

The dominant lithology of the Lower to mid-Cretaceous rocks in central Graham Island is a medium to coarse grained, massive sandstone. This sandstone generally has no primary structures, but rare cross- and parallel-laminations, as well as swale cross-lamination (Fig. 3), are found. The sandstone is light or dark grey to greenish black, with abundant bioturbation defined by small (few millimetres wide) traces of dark finer material. Beds 2-15 cm thick, composed predominantly of molluscs, are also a common facies, as are belemnitic sandstones. Coalified wood fragments and less abundant concretions are also found.

Mudstone and conglomerate layers and lenses can be found interbedded with the sandstones. The mudstones are similar to the mudstones of the Haida Formation, described below. The conglomerates are supported by a medium- to coarse grained sandstone matrix, and clast size ranges from 2-5 cm. The pebbles are subrounded to well rounded and well sorted. Compositions are mainly volcanic with minor constituents of plutonic rocks and mud clasts. The conglomerates are present as layers or lenses 5-50 cm thick that may have internal lenses of sandstones. Conglomerate layers with thickness of one to three pebbles are found as low angle crossbeds. Some isolated pebbles and cobbles are scattered within the sandstones. When weathered, the rocks are greenish to brownish. They are commonly well indurated when weathered, but they may also be recessive or form spherical nodules.

Cretaceous mudstone

The mudstone and shale of the same formations are described as one unit. The facies generally consist of massive blue-grey mudstone with very weak or no bedding plane fissility. In places the mudstone has well developed bedding plane fissility or cleavage and can be classified as shale.

Sandstone interbeds are uncommon, but in places layers of siltstone and sandstone occur. The mudstone becomes gradually sandier upsection grading into the Skidegate Formation.

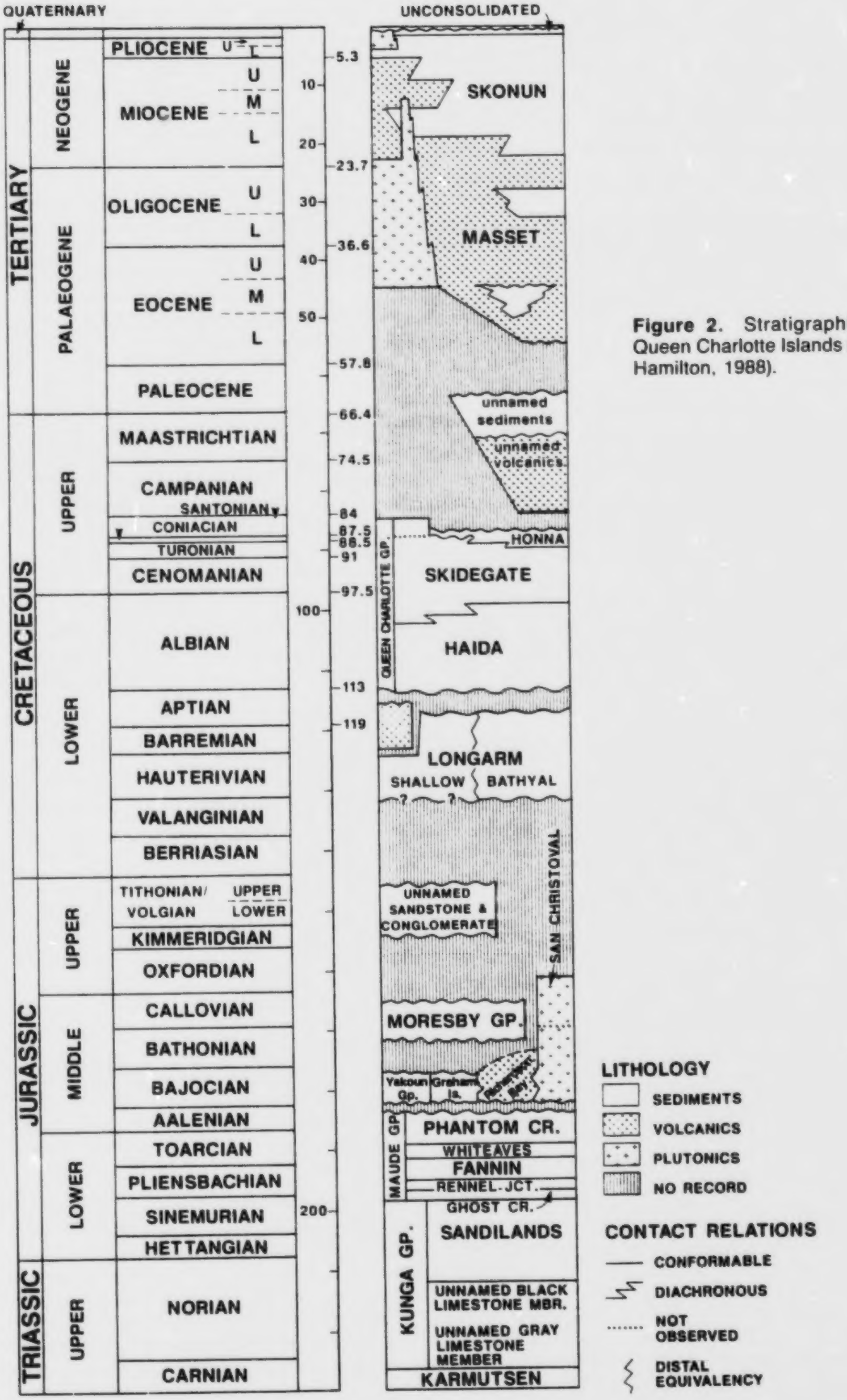
Calcareous concretions are abundant in parts of the mudstone. They reach 50 cm in diameter, but more commonly are potato-shaped, grey concretions, 2-5 cm across. The weathered residue of these concretions is commonly very soft, dark brown, earthy looking clay. In a few outcrops smaller black concretions occur in addition to the larger, more common grey ones.

The mudstone is brownish purple on weathered surfaces and green on fresher surfaces; it fractures into small angular pieces less than 4 mm wide. In areas with abundant intrusions, the rocks have a waxy appearance and are more indurated.

Skidegate Formation

The Skidegate Formation consists of interbedded sandstone, siltstone, and mudstone with well defined bedding. The sandstones are generally lighter coloured than the finer grained lithologies. The proportion of the sandstone varies from less than 20 % to more than 60 % through the section.

Basal scour, normal grading, and parallel lamination are common in the sandstones. Some outcrops in the mapped area show impressive sedimentary structures, including convolute bedding, pseudonodules (sandstone balls), sandstone dykes, and flame structures. The sandstones are probably A and B and possibly C divisions of the Bouma turbidite sequence, with the mudstones representing the E division. Rocks of this formation are fairly well indurated and good


QUATERNARY
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CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
LOWER
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
JURASSIC
UPPER
TITHONIAN/ VOLGIAN
UPPER
LOWER
KIMMERIDGIAN
OXFORDIAN
MIDDLE
CALLOVIAN
BATHONIAN
BAJOCIAN
AALENIAN
LOWER
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PLIENSBACHIAN
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10
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87.5
88.5
91
97.5
113
119
UNCONSOLIDATED
SKONUN
MASSET
unnamed sediments
unnamed volcanics
HONNA
QUEEN CHARLOTTE GP.
SKIDEGATE
HAIDA
LONGARM
SHALLOW
BATHYAL
?
?
UNNAMED SANDSTONE & CONGLOMERATE
SAN CHRISTOVAL
MORESBY GP.
Yakoun Gp.
Graham Is.
Richardson Bay
MAUDE GP.
PHANTOM CR.
WHITEAVES
FANNIN
RENNEL. JCT.
GHOST CR.
KUNGA GP.
SANDILANDS
UNNAMED BLACK LIMESTONE MBR.
UNNAMED GRAY LIMESTONE MEMBER
KARMUTSEN
LITHOLOGY
SEDIMENTS
VOLCANICS
PLUTONICS
NO RECORD
CONTACT RELATIONS
CONFORMABLE
DIACHRONOUS
NOT OBSERVED
DISTAL EQUIVALENCY

Figure 2. Stratigraphic column for the Queen Charlotte Islands (after Cameron and Hamilton, 1988).

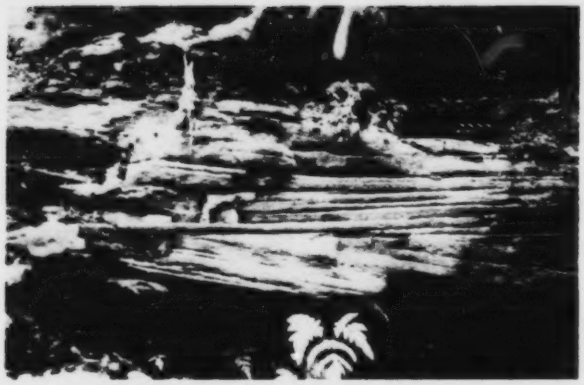

Figure 3. Swale crossbedding in sandstone of the Longarm Formation.

bedding plane fissility is rare in unweathered sequences. The rocks weather shades of brown and break into irregular platy to cubic pieces.

Honna Formation

The Honna Formation consists mainly of conglomerates with minor amounts of sandstone and mudstone. The conglomerates are matrix supported with clast diameters ranging from less than 5 mm to more than 25 cm; the average is 3-4 cm. Clasts are made up of well rounded quartz, quartzite, and plutonic rocks, less rounded volcanic rocks, and angular to rounded sedimentary rocks. The matrix is a medium to coarse grained sandstone.

The sandstone facies of the Honna Formation is a light blue, well indurated, massive, fine to coarse grained sandstone. Generally, there are no primary structures, although some cross-and parallel-laminations are present. The sandstones range from 10-30 cm in thickness, with interbedded pebbly layers, to more than 10 m thick sequences without any conglomerate present.

A third facies of the Honna Formation is a sequence of interbedded sandstone and mudstone which appears similar to the Skidegate Formation. This facies occurs as lenses 1-2 m thick within the conglomerate and sandstone.

Conglomerates are found interbedded with rocks of the Skidegate Formation, generally with basal Honna beds concordant on top of the Skidegate Formation (Fig. 4). Near the base of the conglomerate, clasts of mud and interbedded sandstone and mudstone are abundant and may exceed 50 % of total clasts, these clasts can have long axis of over 50 cm (Fig. 5). Abundant mud clasts are also present in the sandstone of the Honna Formation.

STRUCTURE

Structures observed in Cretaceous rocks in central Graham Island are dominated by faults with minor offset. However, the distribution of Cretaceous lithologies in the area can be easiest explained by the presence of additional faults with hundreds of metres of offset. The trend of these map-scale faults is mainly northwest with fewer trending northeast; none of these faults has been observed in the field.

Most folds are map-scale; few folds were seen in outcrop. The general dip of Cretaceous rocks in central Graham Island is easterly in northern parts of the area and southwesterly in the southernmost area. Because Cretaceous units underwent fewer deformational phases than the Jurassic strata, structures in the Cretaceous rocks in central Graham Island are not as pronounced as some seen in Jurassic strata (Hesthammer, 1990; Indrelid et al., 1990).

Folds

Folds on outcrop scale were rarely seen in the field, but those recorded are generally gentle with no axial planar cleavage. In some outcrops in the western part of the area, Cretaceous shale is folded in open to close folds which contain southwest-dipping to vertical axial planar cleavage.

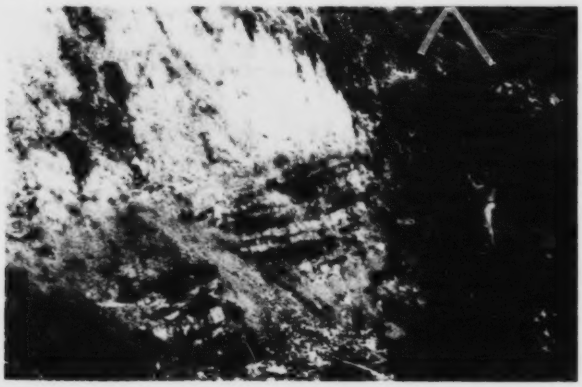

Figure 4. Conformable contact with conglomerate of the Honna Formation overlying the Skidegate Formation.

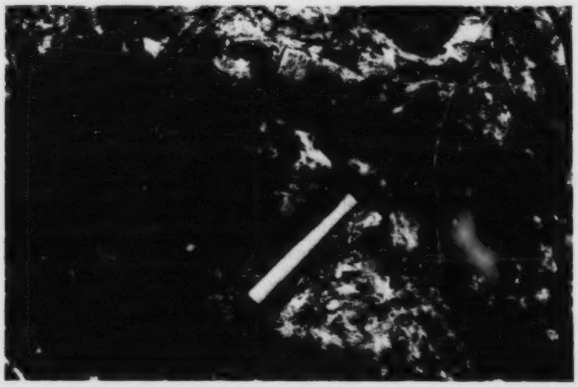

Figure 5. Large clasts of interbedded sandstone and mudstone in the Honna Formation.

Map-scale folds are present in several areas and have accommodated variable amount of shortening. South of Yakoun Lake, Cretaceous rocks are steeply dipping to overturned and folded in close northwest-trending folds. A few kilometres east of this belt of strongly deformed Cretaceous rocks the Longarm Formation is gently folded into northwest-trending folds. This different fold style, which results from different responses to the applied stress, may be related to the proximity to the belt of strongly deformed rocks in the Long Inlet area (Lewis and Ross, 1988; Haggart et al., 1989).

Faults

The faults in Cretaceous rocks fall roughly into two dominant orientations — one set trending northeast, the other southeast. Both sets consists of faults with dips from 60° to vertical. Where determination of relative motion was possible, most faults have a dominant strike-slip component. Where the sense of the slip is possible to deduce from fibrous slickensides, the majority of faults have sinistral movement. It should be emphasized, however, that for more than 50 % of the faults the sense of movement was not possible to determine and that slickensides only indicate the latest movement on the fault surface. The offsets of the faults recorded in outcrops are mostly of the scale of 5-20 cm. In some areas, however, these faults are spaced tens of centimetres apart and total offset over a zone of such faults could be considerable.

DISCUSSION

There are indications of a post-Late Cretaceous compressional event in central Graham Island. The steeply dipping to overturned Cretaceous strata by Yakoun Lake and the folding farther east and north are all results of this compressional event. The general northwesterly trend of the associated structures suggests that the compression was directed northeast to southwest.

The normal faults inferred from the regional distribution of Cretaceous and Jurassic units are probably results of the periodic extensional that may have continued until the late Tertiary (Thompson and Thorkelson, 1989).

Strike-slip faults are known to form both in compressional and extensional tectonic settings. The abundant strike-slip faults observed in the mapped area are very young structures, and they are present in Tertiary volcanic rocks (Haggart et al., 1990). Based on orientation and sense of offset in central Graham Island, these faults are interpreted to have formed during the Tertiary extension and/or compression described by Lewis (1990).

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Structural interpretation of Upper Triassic and Jurassic units exposed on central Graham Island, Queen Charlotte Islands, British Columbia[1]

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Hesthammer, J., Structural interpretation of Upper Triassic and Jurassic units exposed on central Graham Island, Queen Charlotte Islands, British Columbia; in *Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 11-18, 1990.*

Abstract

Jurassic rocks of central Graham Island include interbedded shales, siltstones, and sandstones of Early Jurassic age (Hettangian to Aalenian) and unconformably overlying Middle Jurassic (Bajocian) volcanic rocks and volcanic-derived sedimentary rocks. Major folds in these strata trend northwest; a minor fold set trends northeast. Large-scale thrust faults and younger normal faults are subparallel to the major folds. A minor fault set trending northeast is probably related to strike-slip faulting. Numerous strike-slip faults seen in outcrop may reflect the latest deformation phase. Detachment surfaces occur throughout the Peril and Sandilands formations of the Kunga Group, providing décollements for the thrust faults.

Résumé

Les roches jurassiques de la partie centrale de l'île Graham comprennent des schistes argileux siltstones et des grès interstratifiés du Jurassique inférieur (Hettangien à Aalénien) sur lesquels reposent en discordance des roches volcaniques et des roches sédiments dérivant de roches volcaniques du Jurassique moyen (Bajocien). Des plis importants de ces couches ont une direction nord-ouest alors qu'un ensemble de plis mineurs a une direction nord-est. Des failles inverses et des failles normales plus jeunes à grande échelle sont presque parallèles aux plis importants. Un ensemble de failles mineures de direction nord-est est probablement lié à la formation de failles à rejet horizontal. De nombreuses failles à rejet horizontal observées en affleurement peuvent refléter la dernière phase de déformation. On trouve des surfaces de décollement partout dans les formations de Peril et de Sandilands du groupe de Kunga qui fournissent des décollements pour les failles inverses.

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INTRODUCTION

Three months were spent during the 1989 field season mapping Upper Triassic through Cretaceous rocks on central Graham Island as a part of an MSc thesis at the University of British Columbia. The main purpose of the study is to outline the Mesozoic stratigraphy and structural geology in the area. Because of dense vegetation, outcrop in the area is largely restricted to roadcuts and stream exposures. This report emphasizes the structural geology of the Upper Triassic and Jurassic rocks exposed in the map area. A brief introduction to the stratigraphy will be given.

STRATIGRAPHY

Rocks exposed on central Graham Island include Upper Triassic limestone and Jurassic, Cretaceous, and Tertiary sedimentary and volcanic rocks. The following outlines the stratigraphy of the Upper Triassic and Jurassic strata (Fig. 1, 2); Cretaceous strata are treated by Indrelid (1990).

Intrusive rocks in the map area are limited to dykes that may be feeders for the volcanic rocks of the Yakoun Group and the Masset Formation. Only low-grade metamorphism and contact metamorphism have been observed.

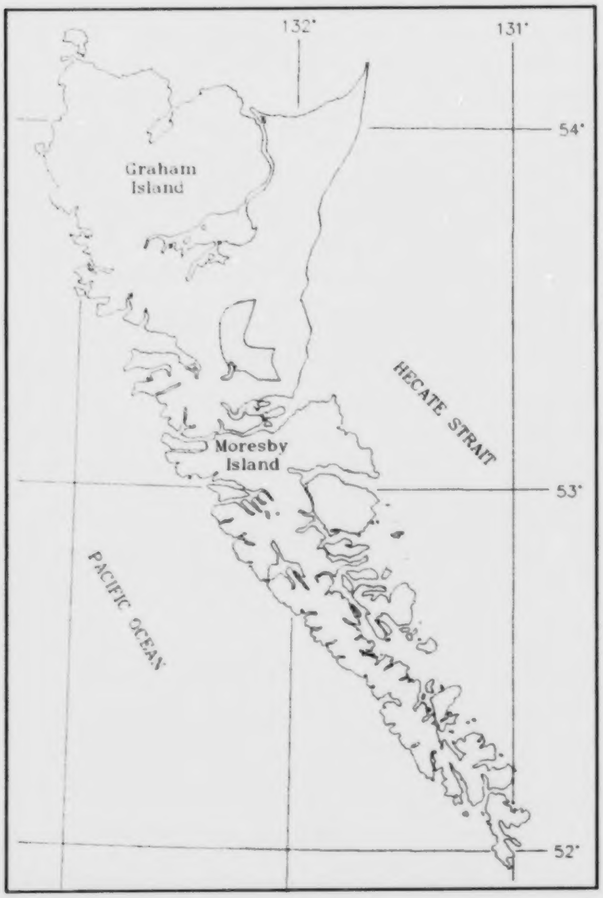

Figure 1. Exposures of Upper Triassic and Jurassic rocks on central Graham Island (stippled area).

Series	Stage	Group	Formation
Late Jurassic	Tithon.-Kimm.		unnamed
Middle Jurassic	Callovian to Bathonian	Moresby	Alliford
			Newcombe
			Robber Point
	Bajocian	Yakoun	Graham Island Richardson Bay
	Aalenian	Maude	Phantom Creek
Early Jurassic	Toarcian		Whiteaves
	Pliens-bachian		Fannin
			Ghost Creek
	Sinemurian	Kunga	Sandilands
	Hettangian		
Late Triassic	Norian		Peril
	Carnian		
			Sadler Limestone
			Karmutsen

Figure 2. Stratigraphy of Upper Triassic and Jurassic rocks on the Queen Charlotte Islands (adapted from Cameron and Hamilton, 1988).

Upper Triassic and Lower Jurassic rocks in the map area belong to the Kunga Group and the Maude Group, and represent a conformable sequence.

Kunga Group

Peril Formation

The Peril Formation consists of calcareous, interbedded, 2-20 cm thick shales, siltstones, and sandstones. The formation was found at only two places in the map area. In one location, limestone rich in *Monotis subcircularis* is seen. This fauna is characteristic of the upper part of the unit (Carter et al., 1989). The Peril Formation was also examined in surrounding areas during the 1989 field season (see discussion).

Sandilands Formation

The Sandilands Formation is a sequence of laminated to thinly bedded turbiditic shales, siltstones, and sandstones. The dominant lithology is 2-12 cm thick, black-grey siliceous sandstone and argillite beds, interlayered with thinly laminated siltstone and shale beds. Thin greenish tuff layers are common throughout the section. Sandstone layers up to 1 m thick occur in places and are most common at the base of the formation.

Maude Group

The Ghost Creek Formation is composed of dark grey to black shale to silty shale with well developed bedding-plane fissility.

The Fannin Formation gradationally overlies the Ghost Creek Formation. The lower part contains 5-15 cm thick siltstone and sandstone beds interbedded with thin shale layers. Towards the top, the sandstone layers are less than 1 m thick and slightly more calcareous. Calcareous concretions, commonly highly fossiliferous, are abundant throughout the formation.

The Whiteaves Formation is typified by grey-weathering shale with abundant calcareous concretions. Well preserved ammonites are common as are grey ash beds. The shale is fissile and very friable.

The dominant lithology of the stratigraphically overlying Phantom Creek Formation is fine to coarse grained sandstone and silty shale. Belemnites and bivalves are abundant. Cryptocrystalline chamosite ooliths are common in some of the sandstone layers.

Yakoun Group

The Yakoun Group overlies the Phantom Creek Formation with an angular unconformity or disconformity. An angular unconformity between the Yakoun Group and the Sandilands Formation is observed in one outcrop.

The Yakoun Group contains both primary and reworked volcanic material. Coal and wood fragments are abundant. Cameron and Tipper (1985) defined two formations of the Yakoun Group; the Richardson Bay Formation and the Graham Island Formation. Due to the diverse lithology of the Yakoun Group in central Graham Island, however, I have found it useful to map several lithologic types, rather than use the formal formation definitions.

The sedimentary rocks of the Yakoun Group have a diverse composition and are laterally discontinuous. The lowermost part of the group on central Graham Island consists of finely laminated, interbedded sandstone, siltstone, shale, and tuff layers. In addition, sandstone layers up to 1 m thick are found interbedded with 2-10 cm thick shale and tuff layers. Overlying and possibly interbedded with these lithologies are red-brown weathering shale and tuff layers, and poorly sorted gravel to cobble conglomerate. Clasts are subrounded to well rounded and composed of volcanic and sedimentary rocks derived from the Yakoun Group and underlying units.

The volcanic rocks of the Yakoun Group consist of volcanic breccia, volcanic conglomerate, and volcanic flows, all interbedded with sedimentary rocks. The volcanic component of the Yakoun Group increases in abundance to the east. The rocks range from light-coloured felsic to dark-coloured mafic aphanites and aphanite porphyries. The volcanic breccia commonly is composed of clasts that closely resemble the matrix. Clast size varies from granules to cobbles, and sorting is poor. The volcanic conglomerate has clasts of diverse composition. Volcanic clasts are most common, but clasts of plutonic and sedimentary origin are also seen. The clasts are generally rounded and poorly sorted. Clast size varies from granules to cobbles, with rare boulders as large as 2 m across (Fig. 3). The volcanic conglomerate is distinguished from the sedimentary conglomerate by having a greater amount of euhedral feldspar phenocrysts in the groundmass.

All the volcanic rocks of the Yakoun Group have abundant large (2-5 mm) feldspar phenocrysts, and uncommon mafic phenocrysts (1-4 mm). Vesicles and calcite amygdules are abundant and range in size from 1-15 mm.

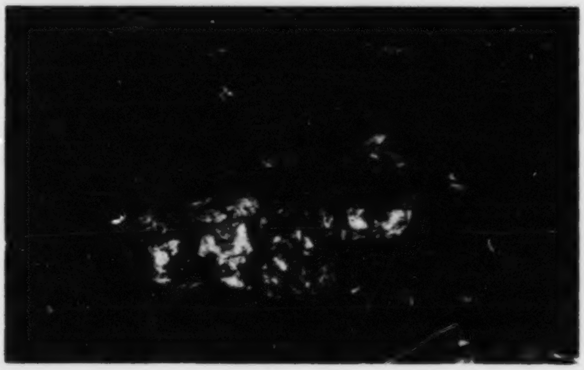

Figure 3. Volcanic conglomerate of the Yakoun Group; the boulder is more than 2 m across.

Despite the diverse lithology of the Yakoun Group, only one traceable rock type has been found, a conglomerate layer more than 20 m thick (Indrelid et al., 1990). Some volcanic rocks of the Yakoun Group closely resemble volcanic rocks of the Masset Formation (Hickson, 1989), complicating the mapping.

STRUCTURES

The most pronounced features in the map area are map-scale northwest-trending folds and faults. A second minor fault set trends northeast and a minor northeast-trending fold set has also been observed. Bedding in the area generally dips towards the northeast. The intensity of folding depends on the lithology and age of the rock units. Cleavage is generally poorly developed and is not observed in hand specimen.

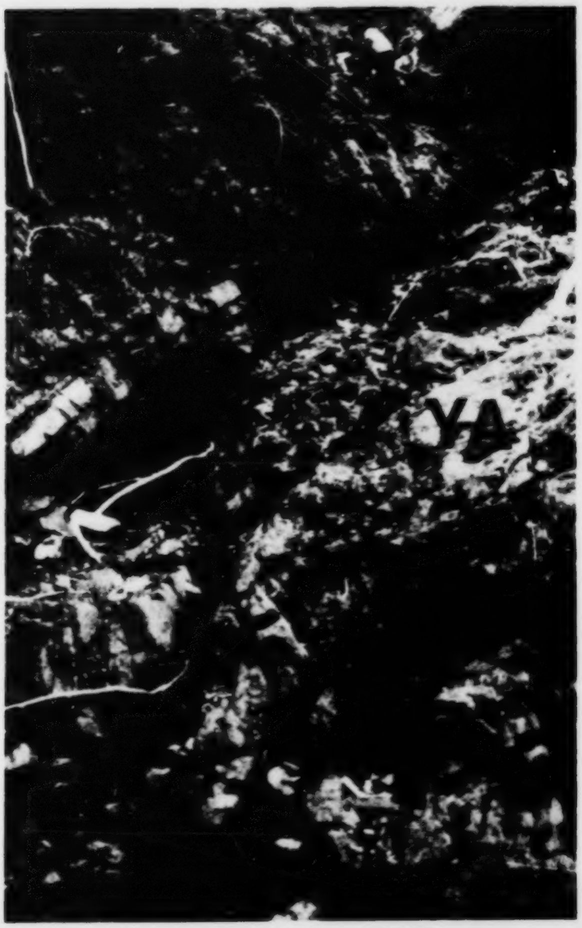

Figure 4. Gently dipping to subhorizontal thrust fault placing the Sandilands Formation (SA) on the Yakoun Group (YA).

Map-scale faults

The map-scale, northwest-trending faults are mainly northeast-dipping thrust/reverse faults and subvertical normal faults (Hesthammer et al., 1989). Map pattern requires several hundred metres offset along these faults. Subhorizontal thrust faults placing rocks of the Sandilands Formation on those of the Yakoun Group (Fig. 4) were found in the area. Due to a lack of exposure, map-scale faults are seldom seen in outcrop, and are therefore inferred from the regional map pattern.

Small-scale faults

The dominant fault type observed in outcrop is an east-northeast-trending oblique fault with a primarily strike-slip offset. Slickensides and striations generally plunge less than 30° and indicate sinistral movement. A minor strike-slip fault set is oriented striking northwest. Mesoscopic dip-slip faults are less abundant and are oriented striking northwest. Offsets of small scale faults are generally less than a few metres. Faults are most abundant in volcanic rocks and sandstones of the Yakoun Group.

Map-scale folds

Northwest-trending map-scale folds have wave lengths from tens of metres to several hundred metres, and amplitudes of tens of metres. The folds are gentle to open and upright to moderately inclined. Vergence is towards the southwest. The map-scale folds are most common in the northwestern half of the map area. Here fold axes are subhorizontal. Older rock units have tighter hinge angles than the younger units. In the southwestern half of the map area, folds are less common, but the dominant orientation is still northwest (Indrelid et al., 1990). Several minor folds trend northeast. As in the northern half of the map area, the oldest rocks have tighter hinge angles than the younger rocks.

Mesoscopic folds

Small scale folds are most abundant in the Sandilands Formation. Common chevron and concentric parallel folds are isoclinal to open and upright to moderate inclined. Fold axes are generally subhorizontal and northwest-trending. Fold axes with moderate to steep plunges occur in some places; fold axes are commonly curvilinear (Fig. 5A). Folds with southwest vergence are most common (Fig. 5B), but northeast vergence is found in a few locations. A second northeast-trending minor fold set can be seen in outcrop. These folds are generally more open and show little or no vergence.

The Maude Group is generally less folded than the Sandilands Formation. Fold axes plunge gently both northwest and northeast, northwest being most dominant. Folds are gentle to open and upright to steeply inclined. A few northwest-trending folds show southwesterly vergence.

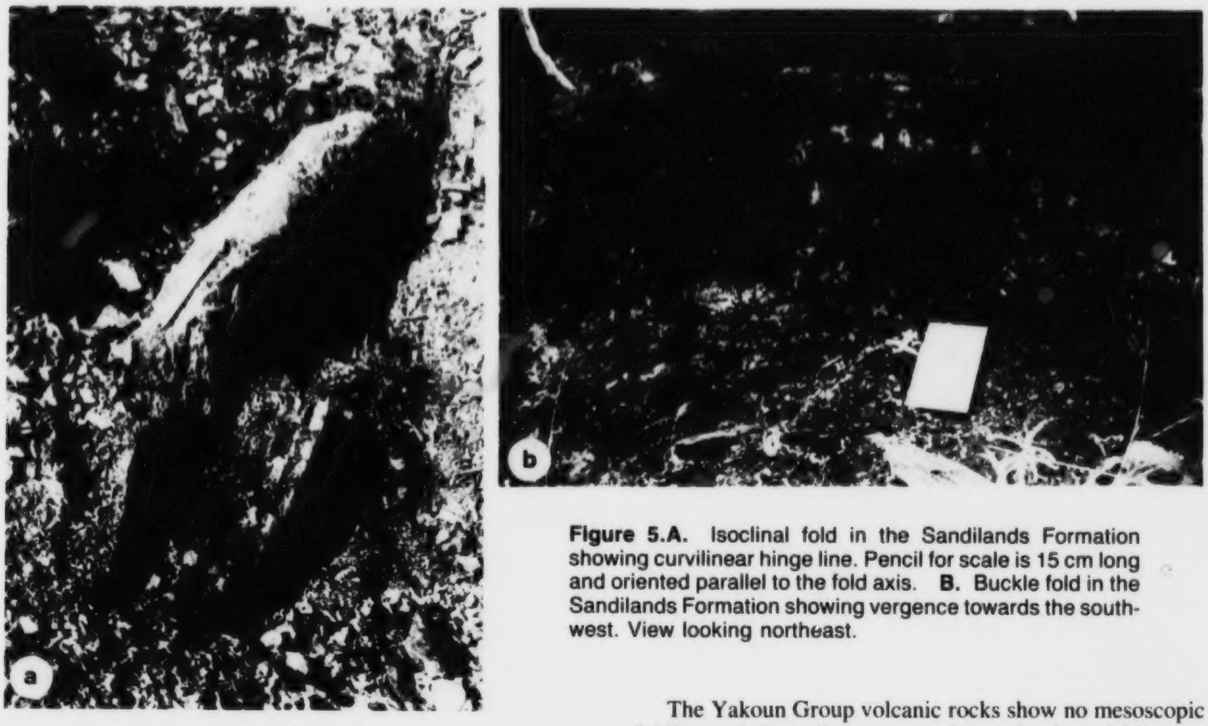

Figure 5.A. Isoclinal fold in the Sandilands Formation showing curvilinear hinge line. Pencil for scale is 15 cm long and oriented parallel to the fold axis. **B.** Buckle fold in the Sandilands Formation showing vergence towards the southwest. View looking northeast.

The Yakoun Group volcanic rocks show no mesoscopic folding and the sedimentary rocks rarely show folding on outcrop scale. The folds observed are gentle to open and upright to steeply inclined. These folds are most commonly found near map-scale thrust faults. Southwestern vergence is seen in one outcrop.

DISCUSSION

Figure 6 shows the main features observed in the Jurassic rocks on central Graham Island. The main structures in the area are northwest-trending folds, normal faults, and thrust faults. These indicate major northeast-southwest oriented compression and extension. The abundance of southwest-verging folds suggests development of northeast dipping thrust faults during this compression. The minor faults striking northeast are most easily interpreted as strike-slip faults on the lateral edges of the thrust sheets (Indrelid et al., 1990).

Younger normal faults cut through the thrust faults, describing a period of northeast-southwest extension. The normal faults in the map area also cut through the Cretaceous rock units in adjacent areas (Indrelid, 1990) dating these as Late Cretaceous or Tertiary.

The angular unconformity at the base of the Yakoun Group indicates that at least one deformation phase took place prior to deposition of this unit. Elsewhere in the islands, folded rocks underlie the unconformity (Thompson and Thorkelson, 1989).

The geometry of contractional faults can be inferred from examination of outcrop-scale structures. The major northwest-trending thrust faults were interpreted previously as listric in geometry (Hesthammer et al., 1989; Indrelid et al., 1990). The abundance of detachment surfaces in the

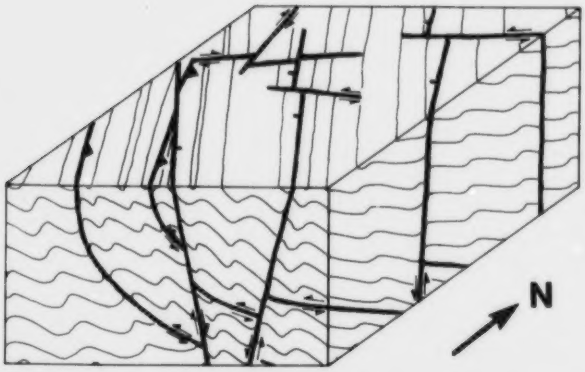

Figure 6. Block-diagram showing main structures observed in the Jurassic rocks on central Graham Island. Thick lines are faults with apparent offset, thin lines represent bedding. The oldest features are northwest-trending thrust faults with associated southwest-verging folds. Strike-slip faults are developed on the lateral edges of the thrust faults; these are cut by northwest-trending normal faults. The youngest structures on the diagram are east-northeast and northwest oriented strike-slip faults.

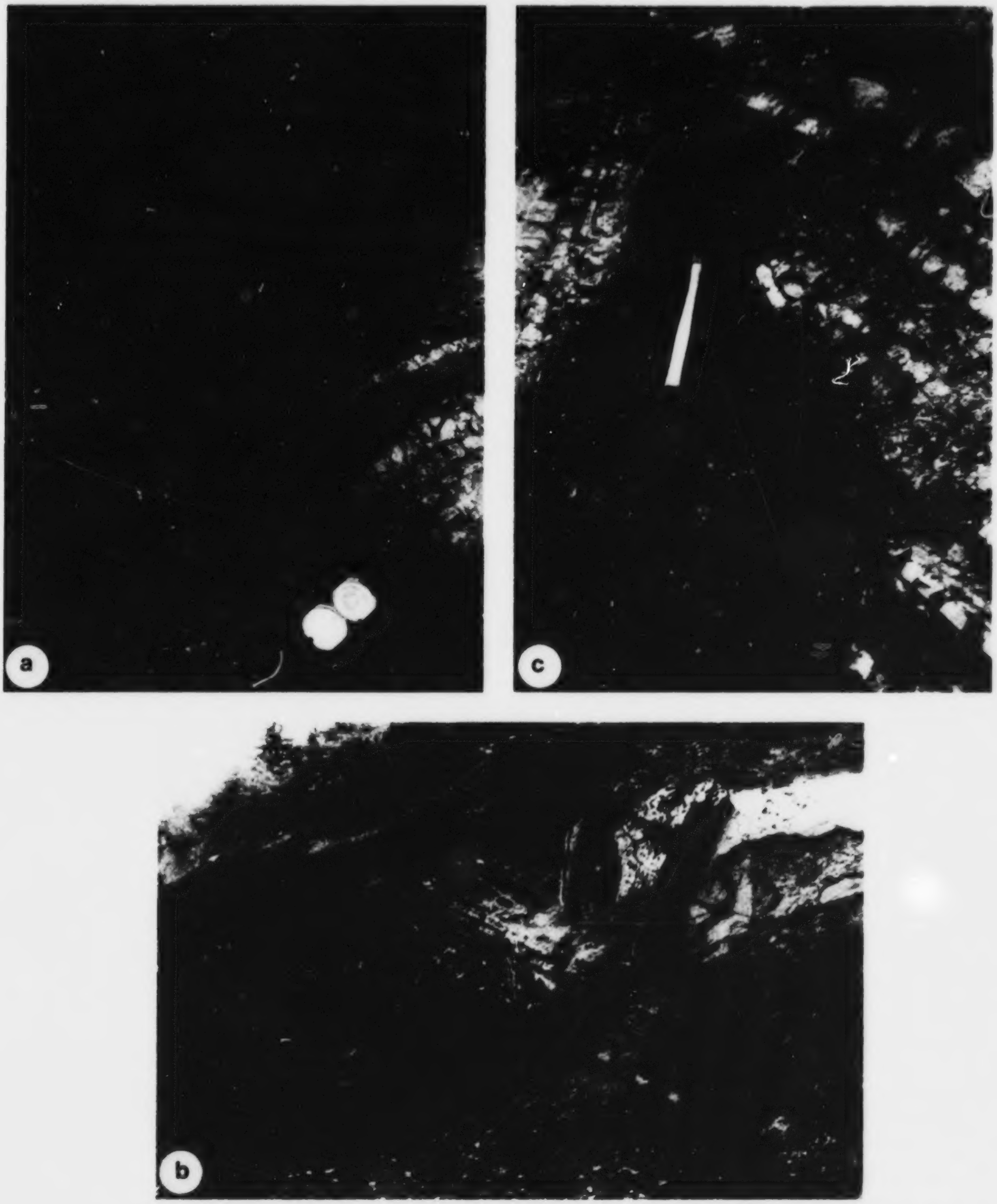

Figure 7.A. Buckle fold and associated detachment surface in the Sandilands Formation. A detachment surface has been created on the upper part of the photograph where the fold dies out. **B.** Typical chevron fold style in the Sandilands Formation. **C.** Collapsed fold hinge in the Sandilands Formation.

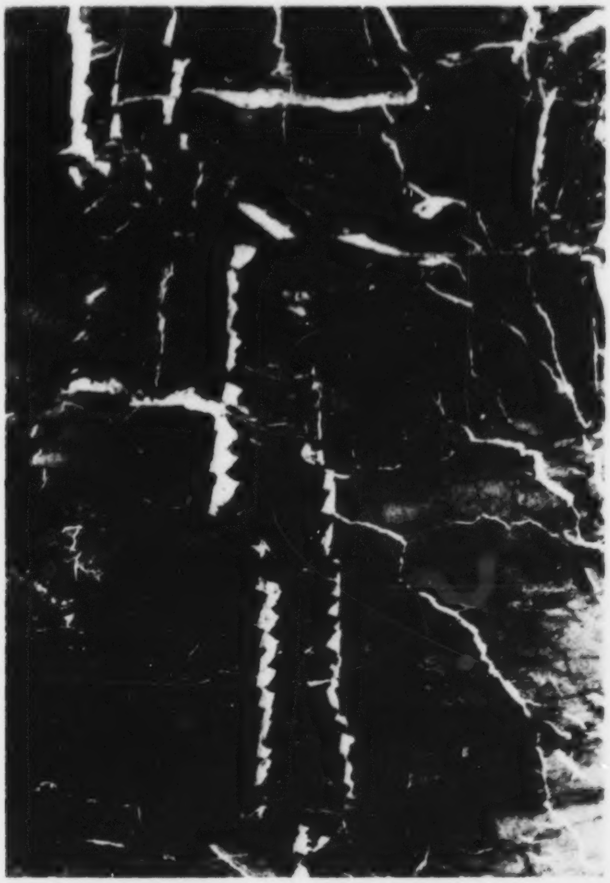

Figure 8. Stylolites and veins in the Peril Formation of the Kunga Group. Arrow shown forscale is 4 cm long.

Peril and Sandilands formations and possibly in the Maude Group indicate that both listric faulting and ramp thrusting were active during deformation.

The mesoscopic strike-slip faults seen in outcrop may have two origins. They may reflect minor structures active during thrust faulting or normal faulting, or they may be related to a late deformational event. The occurrence of strike-slip faults in the Cretaceous units (Indrelid, 1990) and also in the Tertiary Masset Formation (Haggart et al., 1990) indicates that some of the strike-slip faults in the map area are related to a late deformational event. The offset along the strike-slip faults is minor (less than a few metres), but the abundance of faults and the preference for sinistral movement indicates that much total displacement may have taken place.

The presence of several smaller-scale folds with east-west trending fold axes indicates a north-south oriented shortening event. This event appears to be minor relative to the other deformational events described and its age has not yet been determined.

The variation in structural style observed in different lithological units reflects different mechanisms by which shortening is accommodated, and is directly related to lithology. Buckle folding is a result of detachment surfaces commonly observed in outcrops (Fig. 7A). Layer parallel slip takes place easily along these surfaces. The uniform bed thickness of alternating sandstones and shales in the Sandilands Formation leads to buckle folds. Chevron folds occur where the thickness of the sandstone layers is uniform (Fig. 7B). Where rare thicker sandstone layers occur, concentric folds are apparent. Collapsed fold hinges can be seen where a thicker sandstone layer is interbedded with thinner sandstone and shale layers (Fig. 7C). Faults commonly run parallel to bedding and cut into the core of folds, thus solving the space problem created by buckle folding (Indrelid et al., 1990).

Earlier interpretations suggested that the upper part of the Peril Formation provides a décollement above which rocks shorten by folding (Hesthammer et al., 1989; Indrelid et al., 1990). The Peril Formation is mechanically similar to the Sandilands Formation, and the structures observed consequently are similar in style. Observations elsewhere on the Queen Charlotte Islands noted an abundance of calcareous veins in the Peril Formation (Fig. 8). These suggest that some shortening is taken up by pressure-solution rather than folding. Décollements occur throughout the Sandilands and Peril formations, and movement will take place along several smaller décollements rather than along one major surface. This conclusion is consistent with what is observed in Rennell Sound and at Sialun Bay (Lewis and Ross, 1989).

The Maude Group shows little folding, indicating that most of the deformation was accommodated by faults and possibly by bulk shortening.

CONCLUSIONS

The most pronounced structural features in the map area are northwest-trending faults and folds. Both normal faults and thrust faults are recorded. The folds have a strong southwesterly sense of vergence. Minor folds and faults trend northeast. Abundant strike-slip faults with mainly sinistral shear movement are present. Some can be related to the northeast-southwest compression but others are probably related to a later deformation phase.

The most intensely folded rocks in central Graham Island are those of the Sandilands Formation. Younger units are far less folded, with the least folded rocks being those of the Yakoun Group. An angular unconformity at the base of the Yakoun Group restricts at least one deformation phase to pre-Bajocian.

Several detachment surfaces occur throughout the Sandilands and Peril formations. These provide décollements for late or post-Jurassic thrust faulting. Normal faults are subparallel to the thrust faults and postdate these. Major strike-slip faults trend northeast and are probably related to shear movement along the lateral edges of thrust sheets.

The abundance of volcanic rocks in the Yakoun Group becomes greater to the east and may reflect a volcanic centre on the east side of the Queen Charlotte Islands or farther out in Hecate Strait.

ACKNOWLEDGMENTS

I wish to thank the Geological Survey of Canada for field support during the 1989 field season. Jim Haggart, Giselle Jakobs, and Jozsef Pálfy provided essential help in identifying ammonites. Jarand Indrelid, Jim Haggart, Peter Lewis, Charle Gamba, Susan Taite, John Ross, and Bill Barnes are thanked for useful discussion. I am grateful to Chevron Canada Resources for the interest shown in the project and for support with thin sections and SEM analysis.

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Observations on structure and stratigraphy of the Sewell Inlet-Tasu Sound area, Queen Charlotte Islands, British Columbia[1]

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Taite, S., Observations on structure and stratigraphy of the Sewell Inlet-Tasu Sound area, Queen Charlotte Islands, British Columbia; in Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 19-22, 1990.

Abstract

A regional mapping project began in the Sewell Inlet-Tasu Sound area in 1989. Most units mapped in the Queen Charlotte Islands have been recognized in this area; notable exceptions are the Maude Group and the Longarm Formation. Dominant map-scale features are north-trending, steeply dipping faults. Multiple extensional and compressional phases of deformation are indicated; timing is poorly constrained. A transition zone between laterally equivalent Skidegate and Haida facies may reflect basin morphology during Cretaceous time.

Résumé

On a commencé des levés géologiques régionaux dans la région de l'inlet Sewell et de la baie Tasu en 1989. La plupart des unités cartographiées dans les îles de la Reine-Charlotte ont été identifiées dans cette région; les principales exceptions sont le groupe de Maude et la formation de Longarm. À l'échelle de la carte, les structures qui prédominent sont des failles de direction nord et à fort pendage. Des phases multiples de déformation d'extension et de compression; leur âge est toutefois mal défini. Une zone de transition située entre les faciès de Skidegate et de Haida, latéralement équivalents peut refléter la morphologie d'un bassin du Crétacé.

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INTRODUCTION

Regional mapping conducted as part of the Frontier Geoscience Program (FGP) during the 1987 and 1988 field seasons built upon the reconnaissance mapping of Sutherland Brown (1968). Preliminary results from FGP studies include four 1:50 000 scale maps, as well as numerous areas of structural complexity mapped in greater detail (Thompson and Thorkelson, 1989; Lewis and Ross, 1989; Hesthammer et al., 1989). Within the Sewell Inlet-Tasu Sound area, Thompson and Thorkelson (1989) mapped Cretaceous and Tertiary strata both north and south of Sewell Inlet (Fig. 1). Souther (1988, 1989) and Souther and Bakker (1988) examined and characterized dykes of the Selwyn Inlet and the Tasu Sound dyke swarms. Fogarassy and Barnes (1989) examined Cretaceous strata exposed in Sewell Inlet for lithofacies studies and petroleum reservoir potential.

Thompson noted that the dominant northwest structural trends found on Graham Island, northern Moresby Island, and elsewhere in the Queen Charlotte Islands are not present in the Sewell Inlet area. Instead, north to northeast trending structures seem to dictate the distribution of lithologies. In addition, Cretaceous strata on the south shore of Sewell Inlet are steeply dipping to vertical, in contrast to the more moderate attitudes found in most locations. This project was designed to investigate these structures, as well as examine the stratigraphy and structural controls on sedimentation within the Sewell Inlet-Tasu Sound area. This report gives preliminary results from the 1989 field season.

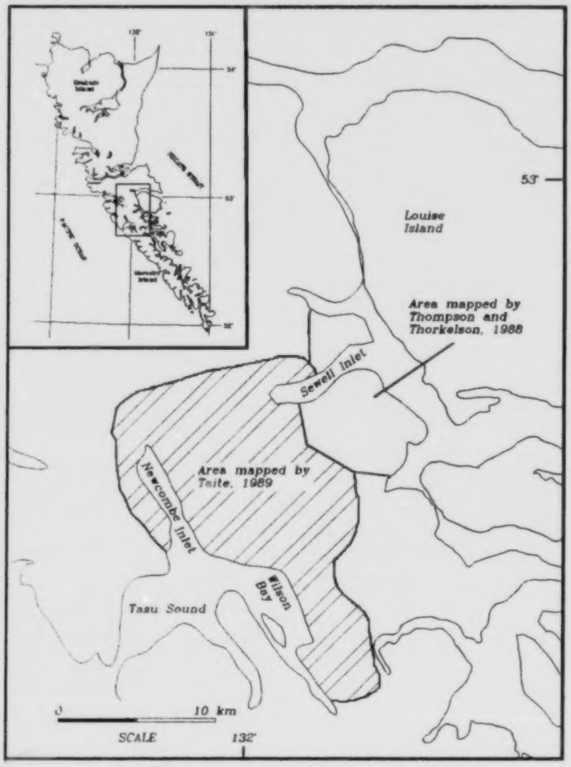

Figure 1. Mapping completed to date in the Sewell Inlet-Tasu Sound area for this study and by Thompson and Thorkelson, 1989.

STRATIGRAPHY

Most of the Mesozoic and Cenozoic map units found on the Queen Charlotte Islands have been observed within the Sewell Inlet-Tasu Sound area. Rocks of the Longarm Formation, the Moresby Group, and the Maude Group have not been identified. Mesozoic and Cenozoic strata have been extensively described by Sutherland Brown (1968), Cameron and Tipper (1985), and others; therefore this report will address only anomalous or interesting occurrences within strata in the area mapped.

Karmutsen Formation

The oldest exposed rocks within the Sewell Inlet-Tasu Sound map area are volcanic rocks of the Carnian (and older?) Karmutsen Formation. These rocks are variably altered with abundant chlorite comprising much of the groundmass and replacing mafic phenocrysts. In outcrop, these rocks generally appear dark green and featureless. However, primary pillow structures occur west of Newcombe Inlet, and locally a strong foliation is developed.

Kunga Group

The Sadler Limestone Peril and thw Sandilands formations compose the Kunga Group. The thickly bedded to massive grey limestone of the Carnian to Norian Sadler Limestone conformably overlies the Karmutsen Formation. Rare fossils have been found in the study area. An anomalous finely laminated grey limestone lithofacies occurs north and east of Newcombe Inlet and is thought to occur near the stratigraphic top of the unit. The transition from the Sadler Limestone to the calcareous shales and limestones of the Norian Peril Formation is abrupt and seldom exposed. Abundant *Monotis* and *Halobia* fossils are found near the top of this unit, along with rare ammonites.

The Peril Formation grades into the bedded shales, sands, and tuffs of the Sandilands Formation over several metres. Extremely thick (up to 10 m) sand layers have been observed near the base of the Sandilands Formation on the west side of Newcombe Inlet. In some locations this unit is highly silicified and appears white in outcrop. When silicified, this lithology becomes extremely resistant, and loses the bedding plane fissility common in most outcrops.

Yakoun Group

Unconformably overlying the Sandilands Formation is the Bajocian Yakoun Group (Fig. 4). Lithologies within the Yakoun Group are highly variable: abundant lapilli tuffs and rare scoria deposits are interlayered with volcaniclastic sandstones, siltstones, and shales. Clast-supported conglomerates and matrix-supported debris flow deposits have been observed. None of these lithologies has demonstrated significant lateral continuity.

Queen Charlotte Group

Cretaceous units exposed within the area mapped include the Haida, Skidegate, and Honna formations of the Queen Charlotte Group. Haida and Skidegate rocks appear to be laterally equivalent; a transition between the Haida and Skidegate formations occupies a northwest-trending zone to the south of Sewell Inlet. Elsewhere in the Queen Charlotte Islands, these formations are of Albian to Turonian age; the age in the Sewell Inlet area is not well constrained. The Skidegate Formation is composed of turbiditic sandstones and siltstones, with sand content between 10 % and 50 %. The Haida Formation rocks are dark grey to black shales and argillites, with scattered fist-sized concretions. Honna Formation conglomerates locally interfinger with Skidegate Formation turbidites on the south shore of Sewell Inlet; these conglomerates may represent submarine channel and overbank levee deposits (Gamba et al., 1990).

Tertiary volcanic rocks

The youngest rocks exposed are Tertiary volcanic and volcaniclastic rocks. Lithologies are highly varied; they include abundant pyroclastic flow deposits, flow banded rhyolites, and volcaniclastic sedimentary rocks. Although many of the lithologies are similar to rocks of the Yakoun Group, which they resemble in outcrop, they were differentiated in the field by being generally more siliceous, less altered, less deformed, and having a more heterogeneous lithic fragment component. These rocks are assigned here to the Masset Formation, but it is possible that they belong to an unnamed Tertiary volcanic suite older than the Masset Formation.

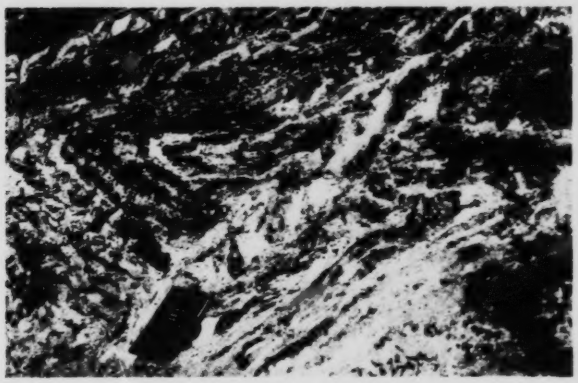

Figure 2. Tight to isoclinal folds and faults in Sandilands Formation rocks east of Wilson Bay.

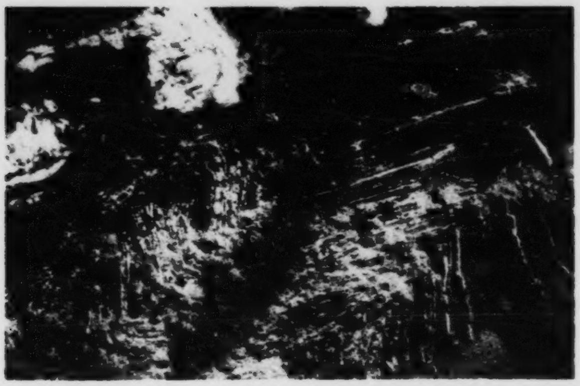

Figure 3. Chevron folds in Sandilands Formation rocks, with a large crosscutting dyke. Fold amplitude is approximately 2 m.

Intrusive rocks

Both the Tasu Sound and Selwyn Inlet dyke swarms described by Souther (1988, 1989) and Souther and Bakker (1988) are present in the area mapped. Each swarm may include dykes related to several different igneous events, such as Yakoun and Masset volcanism and emplacement of the San Christoval plutonic rocks. Pervasive alteration within these rocks makes dating impractical. Both swarms are compositionally heterogeneous, containing dykes with compositions ranging from rhyolitic to basaltic, with most of the dykes being andesitic to dacitic. The abundance of intrusive rocks increases to the south; east of Wilson Bay 30-40 % of outcrops may be composed of intrusive rocks. It is likely that heat flow was very high during emplacement episodes. Vellutini (1988) found a positive correlation between dyke density and thermal maturity; thus the thermal maturity of host sedimentary rocks at Tasu Sound should be high.

STRUCTURE WITHIN THE SEWELL INLET-TASU SOUND AREA

Mesoscopic structures

Mesoscopic structural features vary with lithology and position within the stratigraphic column. Within rocks of the Kunga Group, evidence for both shortening and extension exists. The Sadler Limestone exhibits strongly developed stylolites, commonly at a high angle to bedding. Rocks of the Peril and Sandilands formations accommodated shortening through both east and west verging thrust and reverse faults, and open to isoclinal mesoscopic folds (Fig. 2, 3). All Kunga Group rocks exhibit extensional faults. Crosscutting relationships indicate a complex structural history recorded by the Triassic and Lower Jurassic rocks, including multiple episodes of extension and compression.

Jurassic Yakoun Group rocks lie unconformably on the underlying Kunga Group. The Yakoun-Sandilands contact within the study area ranges from a disconformity to a pronounced angular unconformity (Fig. 4). Folds in the Yakoun Group are seldom observed in outcrop, although where they exist, they are open and upright with minimum amplitudes of tens of metres. Faults, both contractional and extensional, are common in outcrop, commonly juxtaposing the Sandilands Formation against the Yakoun Group along steeply dipping faults with up to tens of metres offset. Crosscutting relationships within the Yakoun again record probable multiple deformation events. Minor reverse faults were seen in Cretaceous lithologies but folds are rare. Normal faults with several orientations have been recorded.

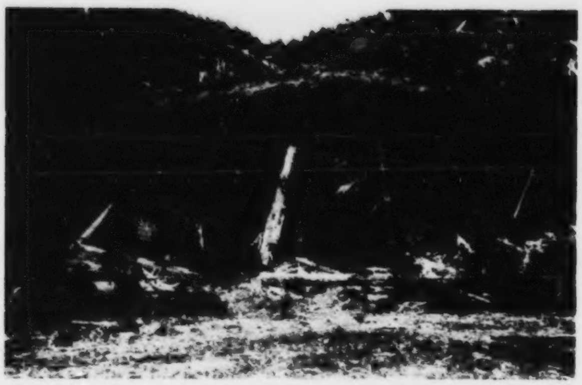

Figure 4. Yakoun Group rocks overlying the Sandilands Formation. Note the high angle of the Sandilands Formation bedding to the unconformity.

In general, the areas of most intense mesoscopic deformation are restricted to discrete zones, which coincide with both the major faults and the areas of most abundant intrusions (Fig. 3). This contrasts with structural styles seen on Graham Island where deformation is distributed more homogeneously throughout the area. Souther (1989) suggested that fundamental structures controlled dyke emplacement and igneous activity may be a manifestation of both deep crustal weakness and extension on deep crustal structures. Souther further suggested that a domain boundary may exists within the Sewell Inlet-Tasu Sound map area, separating areas which are defined by differences in dyke orientation and geochemistry. No map scale structures related to this zone have yet been recognized.

Map-scale structures

Dominant map-scale structural features observed within the Sewell Inlet-Tasu Sound area are steeply dipping north-trending faults. These faults control map-scale distribution of lithologies. Considerable offset is accommodated by the steeply dipping, north-trending faults where they are observed in the oldest rocks. North-trending topographic lineaments can also be seen cutting the Tertiary volcanic rocks. Hickson (1989) stated that similar structures exist within Tertiary volcanic rocks on the west coast of Graham Island. Whether these are primary features formed during the Tertiary, or are reactivated older structures remains uncertain.

CONCLUSIONS

Preliminary results indicate that the map-scale distribution of lithologies is dominated by north to northeast trending structures. The most intense deformation coincides with areas of most intense intrusive igneous activity. Multiple extensional and compressional phases are indicated by both map distribution of lithologies and mesoscopic structures. Constraints on timing are not well defined. Compression existed in both pre-Yakoun and post-Cretaceous times. Extensional regimes were active during the post-Tertiary, and probably earlier; renewed movement on normal faults is likely. Thompson and Thorkelson (1989) invoked northwest-trending fault bound blocks with multiple movement histories to model Cretaceous sedimentation on Moresby Island. The facies change from turbidite facies of the Skidegate Formation to the shale facies of the Haida Formation could reflect differing depositional environments within northwest trending basins during Cretaceous time.

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New timing constraints on Cenozoic deformation in the Queen Charlotte Islands, British Columbia[1]

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Lewis, P.D., New timing constraints on Cenozoic deformation in the Queen Charlotte Islands, British Columbia; in Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 23-28, 1990.

Abstract

Strata exposed at Long Inlet, Queen Charlotte Islands include Lower Cretaceous to Paleogene sedimentary rocks and Upper Cretaceous and Paleogene volcanic rocks. This is the most complete section of this age known in the islands, and mapping at different stratigraphic levels has led to a Late Cretaceous to Tertiary structural model for the area. Four discrete episodes of deformation can be discriminated: Late Cretaceous to early Tertiary shortening, early Tertiary extensional faulting, mid-Tertiary shortening, and late Tertiary to Holocene extensional faulting. This sequence of deformation events will help in relating Tertiary deformation on the Queen Charlotte Islands to contemporaneous Cordillera-wide tectonic events and provides critical on-land constraints for interpreting offshore basin evolution.

Résumé

Des couches affleurant dans l'inlet Long, dans les îles de la Reine-Charlotte, comprennent des roches sédimentaires allant du Crétacé inférieur au Paléogène et des roches volcaniques du Crétacé supérieur et du Paléogène. C'est là la section la plus complète de cet âge connue dans les îles; des levés géologiques effectués à divers niveaux stratigraphiques ont abouti à un modèle structural, pour la région, allant du Crétacé supérieur au Tertiaire. On peut distinguer quatre différents épisodes de déformation qui sont: un raccourcissement allant du Crétacé supérieur au Tertiaire inférieur, des failles d'extension au Tertiaire inférieur, un raccourcissement au Tertiaire moyen et des failles d'extension allant du Tertiaire supérieur au Récent. Cette séquence de déformation permettra de trouver un lien entre la déformation du Tertiaire dans les îles de la Reine-Charlotte et les événements tectoniques contemporains à l'échelle de la Cordillère; elle fournit aussi des contraintes critiques sur terre pour l'interprétation du bassin au large.

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INTRODUCTION

Regional and detailed structural mapping within the northern and central Queen Charlotte Islands in 1987 and 1988 has revealed a structural history involving four episodes of deformation: Middle Jurassic southwest-directed shortening, Late Jurassic to mid-Cretaceous extension and block faulting, Late Cretaceous to Paleogene northeast-directed shortening, and Neogene extensional faulting (Lewis and Ross, 1989, 1990; Thompson and Thorkelson, 1989). The nature and timing of the Tertiary deformation events have been poorly understood, mostly due to a paucity of exposures of well dated, early Tertiary stratified rocks. Over the last year, two new sources of information have shed light on the Tertiary structural history of the region. First, seismic reflection data from Queen Charlotte Sound have provided a clear picture of structures in the offshore

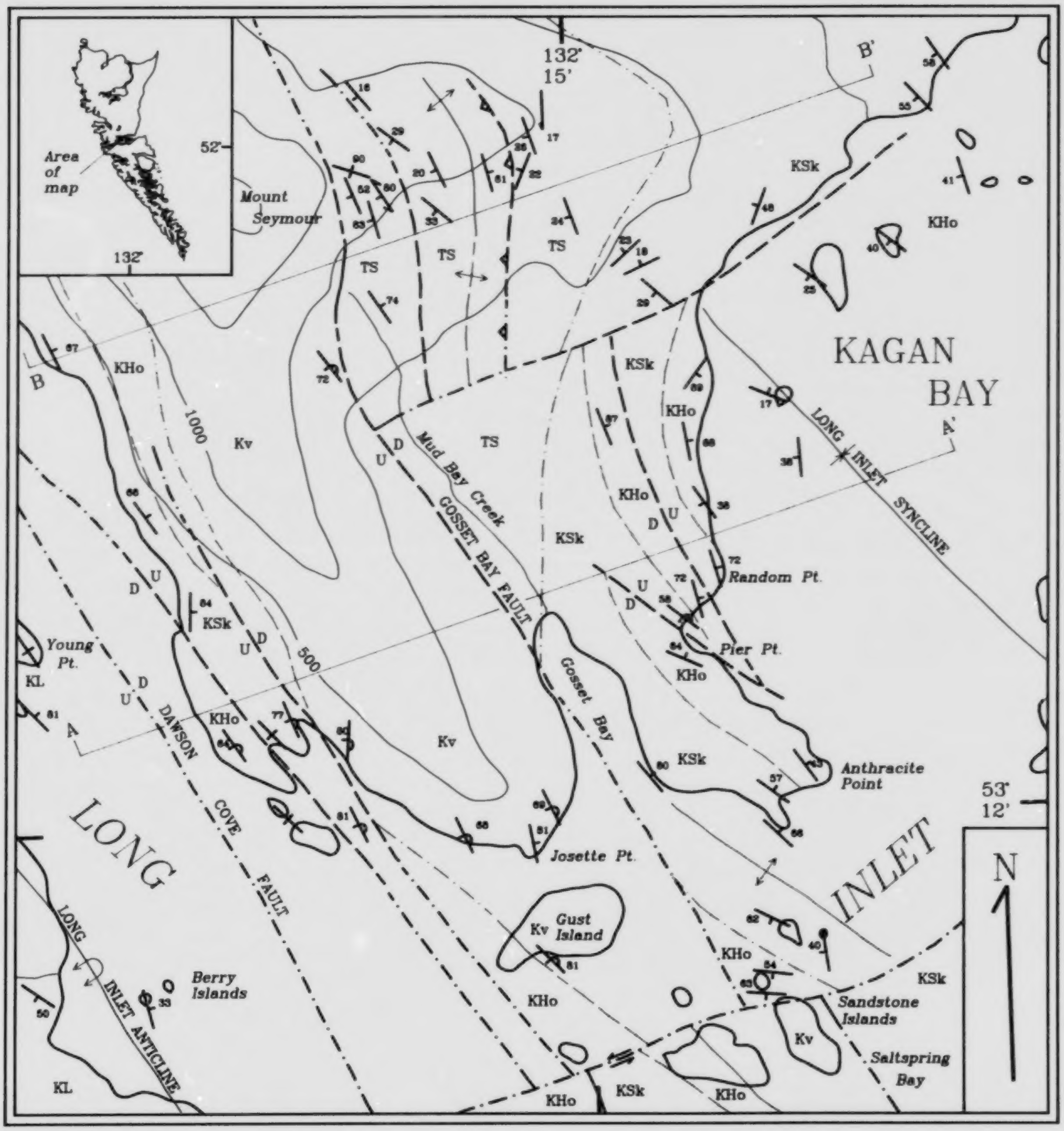

Area of map
52°
132°
132° 15'
53° 12'
N
B
B'
A
A'
Mount Seymour
TS
KHo
KSk
Kv
KL
1000
500
U
D
Mud Bay Creek
GOSSET BAY FAULT
DAWSON COVE FAULT
LONG INLET SYNCLINE
LONG INLET ANTICLINE
KAGAN BAY
LONG INLET
Gosset Bay
Random Pt.
Pier Pt.
Anthracite Point
Josette Pt.
Young Pt.
Gust Island
Berry Islands
Sandstone Islands
Saltspring Bay

Figure 1. A. Structural geology of eastern Long Inlet and western Kagan Bay, Queen Charlotte Islands, British Columbia. B. Interpretative cross-section along section lines shown in Figure 1A. Arrows on faults indicate movement direction of latest offset.

TERTIARY
Early Eocene to Early Oligocene

TS	*Unnamed sedimentary rocks* *black shale, minor sandstone and coal*

CRETACEOUS
Coniacian and younger

Kv	*Unnamed volcanic rocks* *feldspar–phyric andesitic flows and pyroclastic rocks*
KHo	*HONNA FORMATION* *conglomerate and sandstone*

Albian to Lower Turonian

KSk	*SKIDEGATE FORMATION* *interbedded sandstone and shale*

CRETACEOUS AND JURASSIC
Tithonian to Aptian

KL	*LONGARM FORMATION* *sandstone, fossiliferous sandstone, shale, minor conglomerate*

Stratigraphic or intrusive contact
(defined, approximate, assumed)

U
D
Normal or reverse fault
(defined, approximate, assumed; showing sense of offset)

Thrust fault
(defined, approximate, assumed; teeth on upper plate)

Strike–slip fault
(defined, approximate, assumed; showing sense of offset)

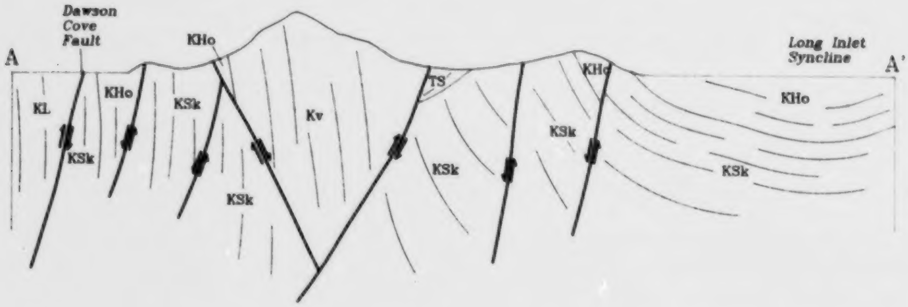
Bedding (inclined, overturned, vertical)

Foliation

Fold axial trace (antiform, synform, overturned antiform)

SCALE

0
2000
metres


A
Dawson Cove Fault
KHo
Long Inlet Syncline
A'
KL
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TS
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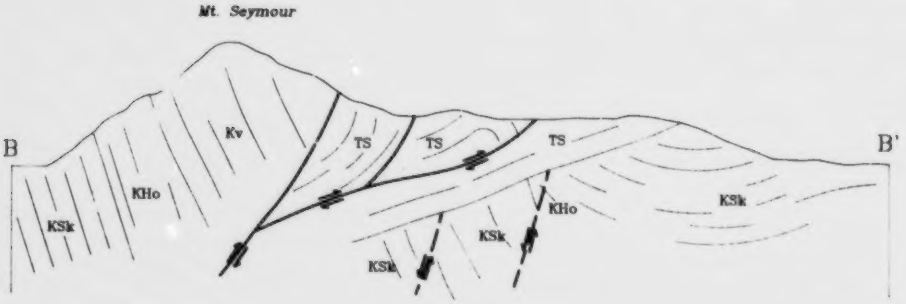
Mt. Seymour
B
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Neogene basin. Second, a previously unmapped, highly deformed sedimentary succession was recognized on southern Graham Island near Long Inlet. Structures within this succession were examined during the 1989 field season, and are described and interpreted in this report.

LOCAL GEOLOGY

On Graham Island, Paleogene sedimentary rocks are exposed discontinuously along creek beds and logging roads north of Gosset Bay, and in creek beds south of Saltspring Bay (Fig. 1A). The dominant lithology at these locations is fissile black nonmarine shale, with minor coal and sandstone layers. Palynomorphs collected from shale samples indicate an Eocene and/or Early Oligocene age for the succession (J. White, personal communication, 1989).

The geology of the area surrounding the Eocene/Oligocene succession is described in detail by Haggart et al. (1989) and Lewis and Ross (1990), and is summarized below. Rocks exposed in this area are sedimentary and volcanic in origin and range in age from Early Cretaceous to Tertiary. They include rocks of the Longarm, Skidegate, and Honna formations and unnamed Cretaceous and Paleogene volcanic successions.

Several generations of structures are present in the Long Inlet area. The oldest mapped structure is the northwest-trending Dawson Cove Fault, which follows the length of Long Inlet and separates strata of the Lower Cretaceous Longarm Formation to the west from those of the mid to Upper Cretaceous Honna and Skidegate formations to the east. R.I. Thompson (personal communication, 1989) infers an episodic Late Jurassic to at least Early Cretaceous offset history for the fault along a steeply dipping surface. Recent biostratigraphic investigations in Cumshewa Channel indicate that in that area the trace of the fault occurs within a continuous Lower to mid-Cretaceous succession, suggesting that offset along it is minor (J.W. Haggart, personal communication 1989).

The Long Inlet Anticline and Long Inlet Syncline represent a major northeast-verging fold pair which trend southeast from Long Inlet across Moresby and Louise islands. These folds locally overturn Upper Cretaceous strata, but do not deform the overlying Paleogene volcanic rocks. Most of the Long Inlet area lies on the steeply dipping, east-facing limb between these two structures.

The Gosset Bay Fault and related faults are northwest-trending structures which cut all Cretaceous strata and the Long Inlet Anticline and Syncline. Movement on these faults is loosely constrained to the Paleogene and/or Neogene, and has a normal sense. Finally, the youngest structures mapped are east-northeast-trending faults which cut steeply through all the above features and have small amounts of left-lateral offset.

STRUCTURES IN EOCENE/OLIGOCENE SEDIMENTARY ROCKS

Map structures

Eocene/Oligocene strata were examined on the ridge east of Mount Seymour and along the creeks leading from this ridge south towards Gosset Bay. In this area, several distinct structural trends are present (Fig. 1A, 1B):

1) The Eocene/Oligocene succession is faulted against Cretaceous volcanic rocks to the west along the Gosset Bay Fault. Bedding in the sedimentary rocks adjacent to the fault is steeply dipping to vertical. These steep bedding dips continue to the east for 300-400 m where they are bounded by a northwest-trending, subvertical brittle fault zone, exposed in creek beds leading from Gosset Bay.

2) East of the steeply dipping section, bedding dips moderately to the west. These west dipping beds are cut by a north-trending, west-dipping thrust fault, located approximately 800 m (map distance) east of the Gosset Bay Fault. The upper plate of the fault contains a map-scale, northwest-trending antiform which is interpreted as a drag feature related to movement on the thrust surface.

3) The basal contact of the Eocene/Oligocene section is not exposed; however, outcrop distribution indicates that it dips gently to moderately to the west. Between Anthracite Point and Random Point, it is not significantly offset by northwest-trending faults in Cretaceous strata which strike directly into the younger rocks. A significant angular unconformity is inferred from the near-vertical dips in Cretaceous strata which directly underlie the gently dipping contact.

Minor structures

In most locations a moderately to strongly developed fissility is present in the shales. This fissility is bedding-parallel or inclined to bedding at small angles (<15°; Fig. 2A); rarely it is at a high angle to bedding. Where fissility is not bedding-parallel, it trends northwest and dips steeply southwest.

Minor faults (offset <10 cm) occur in most outcrops (Fig. 2B). In the steeply dipping beds just east of the Gosset Bay Fault, north-striking, moderately west-dipping faults are most common; these surfaces contain subhorizontal slickensides and offset bedding in a right-lateral sense. Elsewhere, variably dipping, north- to northwest-trending faults are observed; slickensides and offset of bedding record normal movement on these surfaces. Relative timing of the two families of minor faults could not be determined.

DISCUSSION

Prior to the 1989 field season, the timing of folding of mid to Upper Cretaceous rocks was only loosely constrained to the Late Cretaceous or Paleogene. The present finding that Eocene/Oligocene sedimentary strata unconformably overlie these folded Cretaceous rocks places an Early Oligocene younger limit on the timing of this folding. Northwest-trending normal faults that cut the major folds in Cretaceous strata do not cut the Paleogene succession, indicating that the Cretaceous strata also have a pre-Early Oligocene extensional faulting history. This timing is corroborated by Anderson and Greig (1989), who proposed that coeval bimodal plutonism and dyking on the islands support Middle to Late Eocene extension. Folding within the Eocene/Oligocene section represents a younger contractional deformation. This contraction likely modified existing structures, but did not create a new generation of structures within the underlying Cretaceous rocks. However, flat-lying volcanic rocks of probable Oligocene age unconformably overly the deformed Eocene/Oligocene section. These volcanic rocks have not suffered recognizable contractional deformation but are cut by steeply dipping dip-slip faults (Lewis and Ross, 1990). Thus, a latest Mesozoic and Cenozoic structural history having four distinct episodes of deformation is involved:

1) northeast directed shortening, in Late Cretaceous to Early Tertiary time,
2) extensional block faulting, postdating the above shortening but predating deposition of Eocene/Oligocene sediments,
3) northeast-directed shortening, in Oligocene time, and
4) post-Oligocene block faulting, possibly synchronous with extensional structures which cut Neogene strata in Hecate Strait.

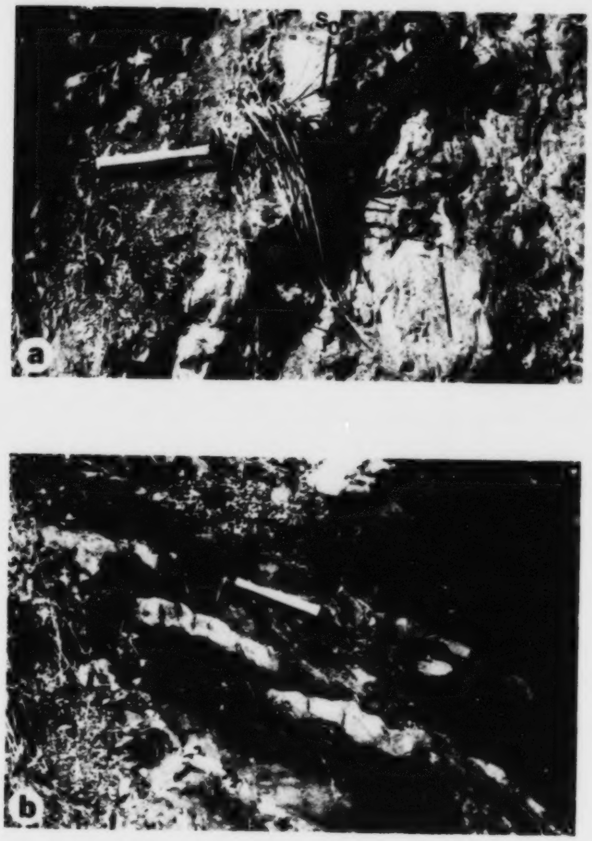

Figure 2. **A.** Outcrop of Eocene/Oligocene shale above Gosset Bay showing fissility (S_1) shallowly inclined to bedding (S_0). **B.** Minor faults in concretionary shale showing approximately 10 cm right-lateral offset. Fault surfaces are oriented approximately north-south.

The geometry and style of the two youngest deformation events is constrained by structures mapped in the Eocene/Oligocene succession. Contractional structures within the succession consistently record east-northeast directed shortening. Cleavage formation is interpreted to be synchronous with this contraction, as cleavage surfaces are parallel to the axial surface of the map-scale fold mapped on the upper plate of the thrust surface. The two faults bounding the subvertical beds in the westernmost exposures were likely active as reverse faults during shortening. Displacement along the faults would have rotated the strata between them, leading to the present steep dips. Minor faults cut both bedding and cleavage and are probably the youngest structures present. Minor extensional faults may be contemporaneous with major northwest-trending extensional faults mapped elsewhere in the Queen Charlotte Islands, and observed in seismic data from offshore regions (K.M.M. Rohr and J. Dietrich, personal communication, 1989). The orientation and offset direction on minor strike-slip faults suggest a conjugate relationship to larger scale, sinistral strike-slip faults in Kagan Bay.

Present outcrop distribution along the trend of the Gosset Bay Fault suggests a multi-stage offset history. North of Gosset Bay, the fault places Cretaceous volcanic rocks to the west against the Eocene/Oligocene succession to the east. Further south, it separates these same Cretaceous volcanic rocks from older Cretaceous strata to the east, although exposure is incomplete. This geometric relationship argues that the Gosset Bay Fault was active both before and after deposition of the Paleogene sediments, an inference which is supported by the presence of a different Cretaceous succession preserved on each side of the fault. Similar fault reactivation scenarios have been invoked elsewhere in the Queen Charlotte Islands to rationalize similar stratigraphic distributions (Thompson and Thorkelson, 1989). Early extensional offset on the Gosset Bay Fault may have led to the formation of the Eocene/Oligocene basin in which the described sedimentary succession was deposited.

The Eocene epoch is recognized as a distinct period in the evolution of the Canadian Cordillera and is characterized by increased magmatism and widespread uplift and extension. Recognition of Eocene/Oligocene sedimentary strata in the Queen Charlotte Islands allows us to postulate ties between deformation events here and Cordillera-wide tectonic events. Unfortunately, any such interpretations are limited by the relatively loose age constraints on the strata used to date deformation in the Queen Charlotte Islands. Further field studies documenting the regional extent of Early Cenozoic deformation in the islands, and further refinement of biostratigraphic ages of Late Cretaceous and Neogene sedimentary strata will be essential in integrating the tectonic model for the Queen Charlotte Islands with the rest of the Cordillera.

ACKNOWLEDGMENTS

I thank James Haggart and the Frontier Geoscience Program for logistical support during the 1989 field season.

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A geological reconnaissance of the Mount Stapleton-Yakoun Lake region, central Queen Charlotte Islands, British Columbia[1]

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Abstract

Two packages of strata comprise the geological succession in the Mount Stapleton-Yakoun Lake region of the central Queen Charlotte Islands. The older is a Cretaceous and Paleogene clastic succession; it is highly deformed and is probably an extension of the major northwest structural trend observed in the Skidegate Channel-Cumshewa Inlet region. The younger includes a mid-Miocene or younger nonmarine sedimentary and volcanic succession, correlative in part with the Skonun Formation, which does not appear to have been involved in post-Early Eocene/Early Oligocene deformation in the region.

Résumé

Deux ensembles de couches constituent la série géologique de la région du mont Stapleton et du lac Yakoun de la partie centrale des îles de la Reine-Charlotte. L'ensemble le plus ancien comprend une série détritique du Crétacé et du Paléogène; il est très déformé et est probablement un prolongement de la direction structurale importante nord-ouest observée dans la région du chenal de Skidegate et de l'inlet Cumshewa. L'ensemble le plus jeune comprend une série de roches sédimentaires et volcaniques non marines du Miocène moyen ou plus jeune corrélative en partie avec la formation de Skonun, qui ne semble pas avoir été déformée au cours de l'événement de l'Éocène post-inférieur/Oligocène inférieur de la région.

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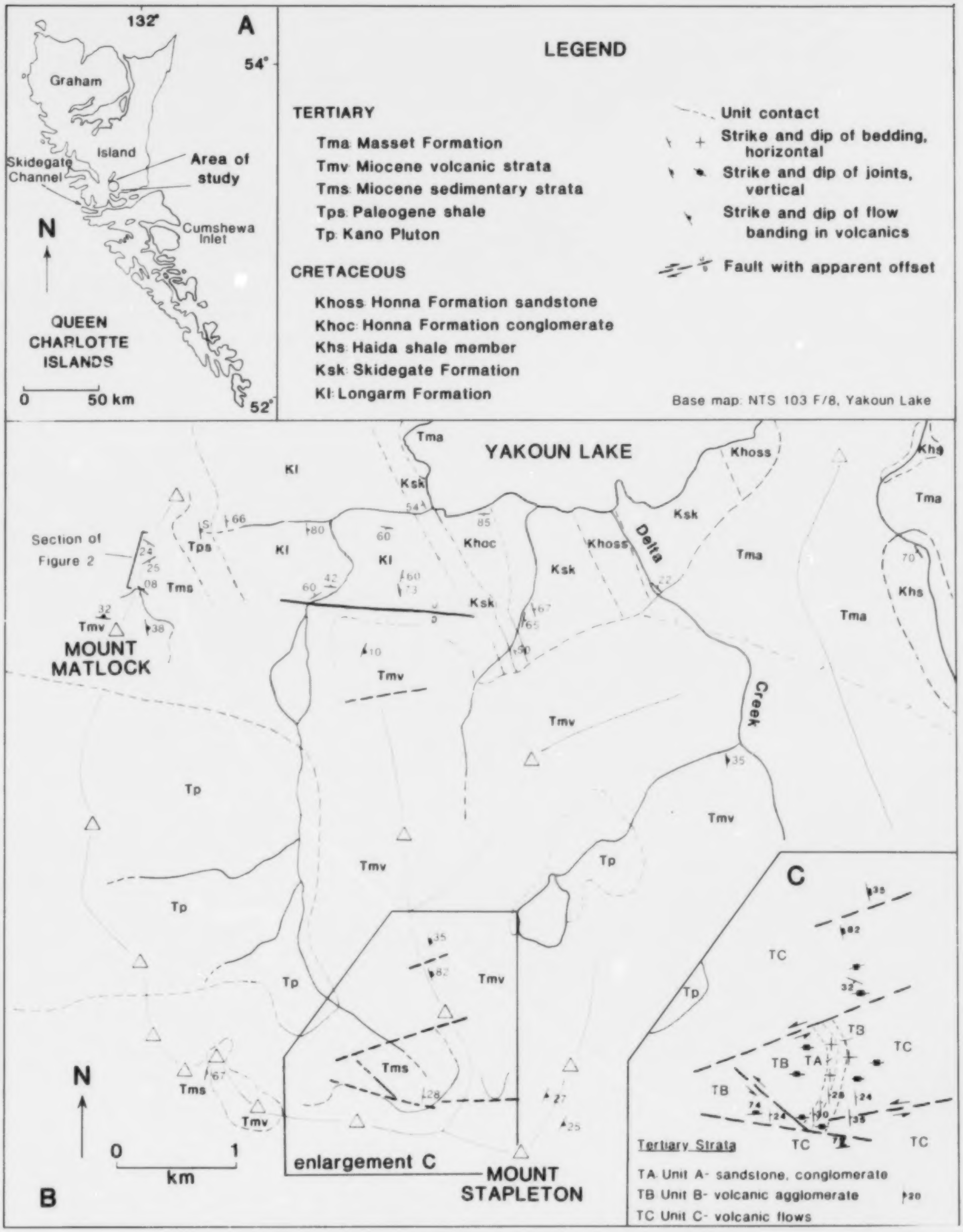
A
132°
54°
52°
Graham
Island
Skidegate Channel
Area of study
Cumshewa Inlet
N
QUEEN CHARLOTTE ISLANDS
0 50 km
LEGEND
TERTIARY
Tma: Masset Formation
Tmv: Miocene volcanic strata
Tms: Miocene sedimentary strata
Tps: Paleogene shale
Tp: Kano Pluton
CRETACEOUS
Khoss: Honna Formation sandstone
Khoc: Honna Formation conglomerate
Khs: Haida shale member
Ksk: Skidegate Formation
Kl: Longarm Formation
Unit contact
Strike and dip of bedding, horizontal
Strike and dip of joints, vertical
Strike and dip of flow banding in volcanics
Fault with apparent offset
Base map: NTS 103 F/8, Yakoun Lake
B
YAKOUN LAKE
Delta
Creek
Section of Figure 2
MOUNT MATLOCK
MOUNT STAPLETON
enlargement C
0 1 km
N
Tma
Tmv
Tms
Tps
Tp
Kl
Ksk
Khoc
Khoss
Khs
C
TA
TB
TC
Tp
Tertiary Strata
TA: Unit A- sandstone, conglomerate
TB: Unit B- volcanic agglomerate
TC: Unit C- volcanic flows

Figure 1. Location map and generalized geological map of the Mount Stapleton-Yakoun Lake region.

INTRODUCTION

The regional geological mapping program in the Queen Charlotte Islands has focused on the central and northern parts of the archipelago over the 1987-1988 field seasons. Because of difficulty of access, however, the area around Mount Stapleton on southern Graham Island (Fig. 1) was not studied in any detail.

The mapping of Sutherland Brown (1968) suggested a straightforward geological interpretation for the Mount Stapleton-Yakoun Lake region. According to his map, an extensive accumulation of Tertiary volcanics of the Masset Formation blankets a Cretaceous clastic succession comprising the Longarm, Haida, and Honna formations. More recent work in the western Skidegate Inlet area, however, has shown that at least some of the volcanic deposits mapped as Masset Formation are actually of Cretaceous age (Haggart et al., 1989). Additionally, palynomorphs from shales in the vicinity of Gosset Bay, Long Inlet are of Early Eocene to Early Oligocene age (J. White, unpublished Geological Survey of Canada fossil report), indicating that at least some of the deposits previously mapped as Cretaceous in that area are actually Paleogene in age.

The objectives of the present study were three-fold: (1) to confirm the presence of Cretaceous deposits in the region, describe their lithology, faunal content, and depositional environments; (2) to compare the Tertiary volcanic succession in the area with the more typical Masset Formation succession exposed in the more northern part of Graham Island; and (3) to ascertain whether the structural trends observed in the western Skidegate Inlet region continue into the Mount Stapleton-Yakoun Lake area.

STRATIGRAPHY

The stratigraphic succession present in the study area is more complicated than originally realized. Several Cretaceous stratigraphic units are present, specifically the Longarm, Skidegate, Haida, and Honna formations. In addition, outcrops of the Paleogene shale succession occurring in Long Inlet are present. Outcrops of the Cretaceous and Paleogene rocks are mainly limited to creek bottom exposures in the heavily forested lower elevations. Overlying the Cretaceous and Paleogene succession, and outcropping at higher elevations, is a thick clastic and volcanic sequence of younger Tertiary age.

Cretaceous

Longarm Formation

Outcrops of the Longarm Formation were noted in the valley west-southwest of the western end of Yakoun Lake (Fig. 1). The most extensive exposures are found north of the lake situated 1.5 km east of the summit of Mount Matlock. At this locality, erosion associated with a major east-west trending fault has produced a deep canyon in which younger volcanics on the south are juxtaposed against Cretaceous strata on the north side of the fault. These strata were originally identified by Sutherland Brown (1968) as Longarm Formation on the basis of their fossil content.

Strata of the Longarm Formation are structurally disrupted but at this locality dip towards the north. They are poorly exposed in the canyon bottom but consist of fine grained sandstone and siltstone containing abundant ammonites, belemnites, and bivalves (*Inoceramus* cf. *paraketzovi* Efimova), suggestive of a Hauterivian age.

In a small tributary draining north from the ridge just east of the above noted lake, additional outcrops of the Longarm Formation are found. Here too, the beds are highly disrupted. Below about 200 m elevation, lithologies present in this creek include greyish green silty shale and shaly siltstone with abundant *Inoceramus* prisms and a few ammonites. Topographically higher outcrops consist mostly of poorly fossiliferous shale with minor interbedded siltstone and sandstone. Based on the fining upward trend observed in the Longarm Formation at other localities in the islands (Haggart, 1989; Haggart and Gamba, 1990), we suggest that the shales in this area probably represent the upper part of the formation.

Other exposures of Longarm Formation are seen adjacent to the study area in creek beds at the head of Long Inlet, southwest of Mount Stapleton. In those exposures, strongly altered shale and siltstone bearing abundant *Inoceramus* prisms are heavily intruded by light coloured igneous rocks.

Skidegate Formation

Outcrops of the Skidegate Formation were only noted at elevations below 250 m in the drainages, such as Delta Creek, that enter Yakoun Lake from the south. The outcrops consist of shale with subordinate turbidite sandstone beds. The strata are highly disrupted and locally overturned in the western part of the map area. To the east they assume a more gentle easterly dip.

Haida Formation

On the eastern edge of the map area, strata of the shale member of the Haida Formation (sensu Haggart et al., 1989) outcrop. The age limits of these strata are poorly constrained but foraminifera of probable Campanian-Maastrichtian age from a locality adjacent to the map area indicate a probable Late Cretaceous age for the shales.

Honna Formation

Two distinct lithofacies are found in rocks mapped as Honna Formation on the shore and south of Yakoun Lake. The first is the typical conglomerate facies characteristic of the Honna Formation at many locations in the Queen Charlotte Islands. These conglomerates were noted in the creek 1 km west of Delta Creek where they are associated with a shale and turbidite succession identified as Skidegate Formation. The Honna Formation conglomerates are relatively thin at this locality, totalling about 50 m in thickness, and interfinger with the Skidegate Formation beds.

Fine to coarse grained quartz- and feldspar-rich sandstone, lacking conglomerate, outcrops locally on the south shore of Yakoun Lake just west and east of the mouth of Delta Creek. These rocks somewhat resemble the sandstones mapped as Honna Formation by Haggart et al. (1989) which outcrop northeast of Young Point in Long Inlet. The exact stratigraphic position of the sandstones in the Yakoun Lake area is, however, uncertain.

Tertiary

Paleogene shale

A localized exposure of black unlaminated shale with extensive iron-rich oxidized horizons was observed in the bed of the creek draining east from the ridge north of Mount Matlock. These distinctive rocks are lithologically similar to black shales of Paleogene age which outcrop east and south of Mount Seymour in Long Inlet. The nonmarine Paleogene shales in Long Inlet contain freshwater molluscs, reach great thickness, and contain local coal beds and thin sandstone horizons.

The black shale found near Yakoun Lake is unfossiliferous and highly deformed. The relationship of these beds with closely associated Longarm Formation sandstones and shales is unknown although presumed to be unconformable. In the Long Inlet area the Paleogene shales unconformably overlie the Skidegate and Honna formations (Lewis, 1990).

Mid-Miocene sedimentary and volcanic succession

Unconformably overlying the Cretaceous and Paleogene succession is a younger Tertiary sedimentary and volcanic sequence. This younger Tertiary sequence consists of two distinct parts: a lower, predominantly sedimentary, succession; and an upper, mostly volcanic, accumulation.

A section was measured through the lower part of this Tertiary sequence on the north ridge of Mount Matlock between about 800 and 500 m elevation (Fig. 1, 2). Pollen samples collected from shales within the measured section indicate a probable mid-Miocene of younger, but pre-Quaternary age. Overlying the measured section are several hundred metres of light-coloured volcanic rocks exhibiting flow banding that form the upper part of the younger Tertiary sequence.

Outcrops of the lower, sedimentary succession also occur at several localities in the bowls on the north side of Mount Stapleton. The sedimentary facies at one of these localities (Fig. 1) were studied in detail. At this locality the sedimentary facies form a sequence approximately 25 m in thickness (Fig. 1, Unit A), which is underlain and covered by a thick succession of volcanic breccias and flow banded volcanics (Fig. 1, Unit B) indicative of subaerial volcanism.

The sedimentary strata at this locality consist of interbedded massive- to reverse-graded framework conglomerates and trough cross-stratified to horizontally bedded sandstones (Fig. 3A). The poorly sorted conglomerates are tabular units up to 2.5 m thick with erosional bases. They exhibit a framework texture composed of clasts of subangular to rounded light-coloured volcanics (90%); granitoids (5%); and sandstone, mudstone, and volcanic glass (5%). The matrix is composed of poorly sorted, coarse to fine grained lithic sandstone.

The associated sandstones are coarse to fine grained, and composed of angular to subangular volcanic grains. The cross-stratified sandstone occurs in units composed of grouped cosets up to several metres in thickness.

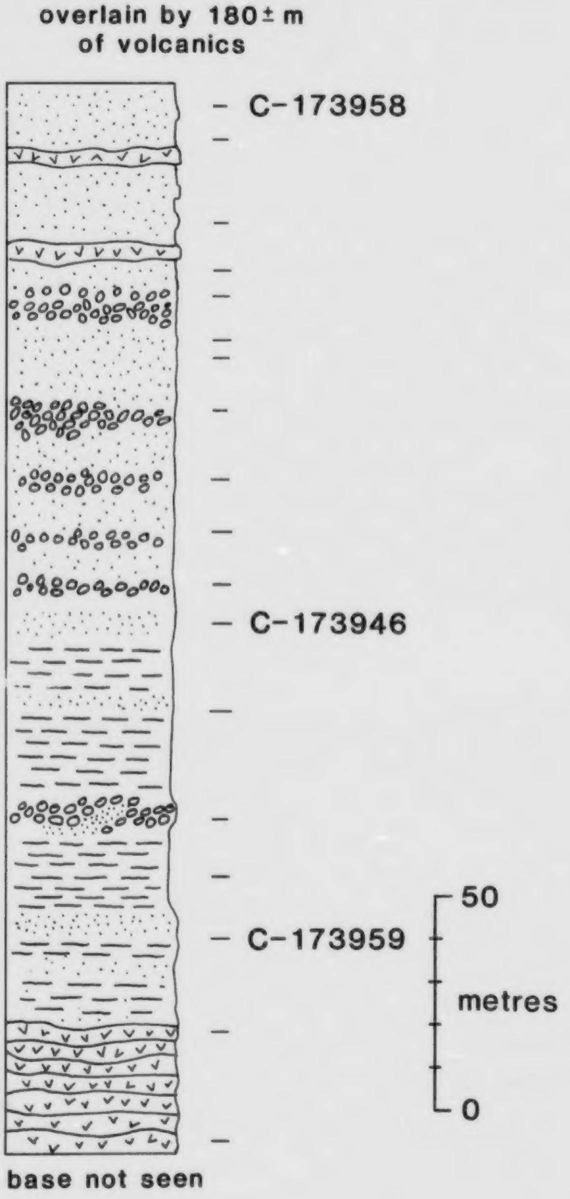

Figure 2. Stratigraphic section through lower part of younger Tertiary succession, north ridge of Mount Matlock. Much of the section is covered and outcrop elevations were determined with altimeter during descent. Outcrops are indicated by horizontal dashes at right of column; lithologies of covered intervals extrapolated from outcrop data. C-numbers are Geological Survey of Canada fossil localities.

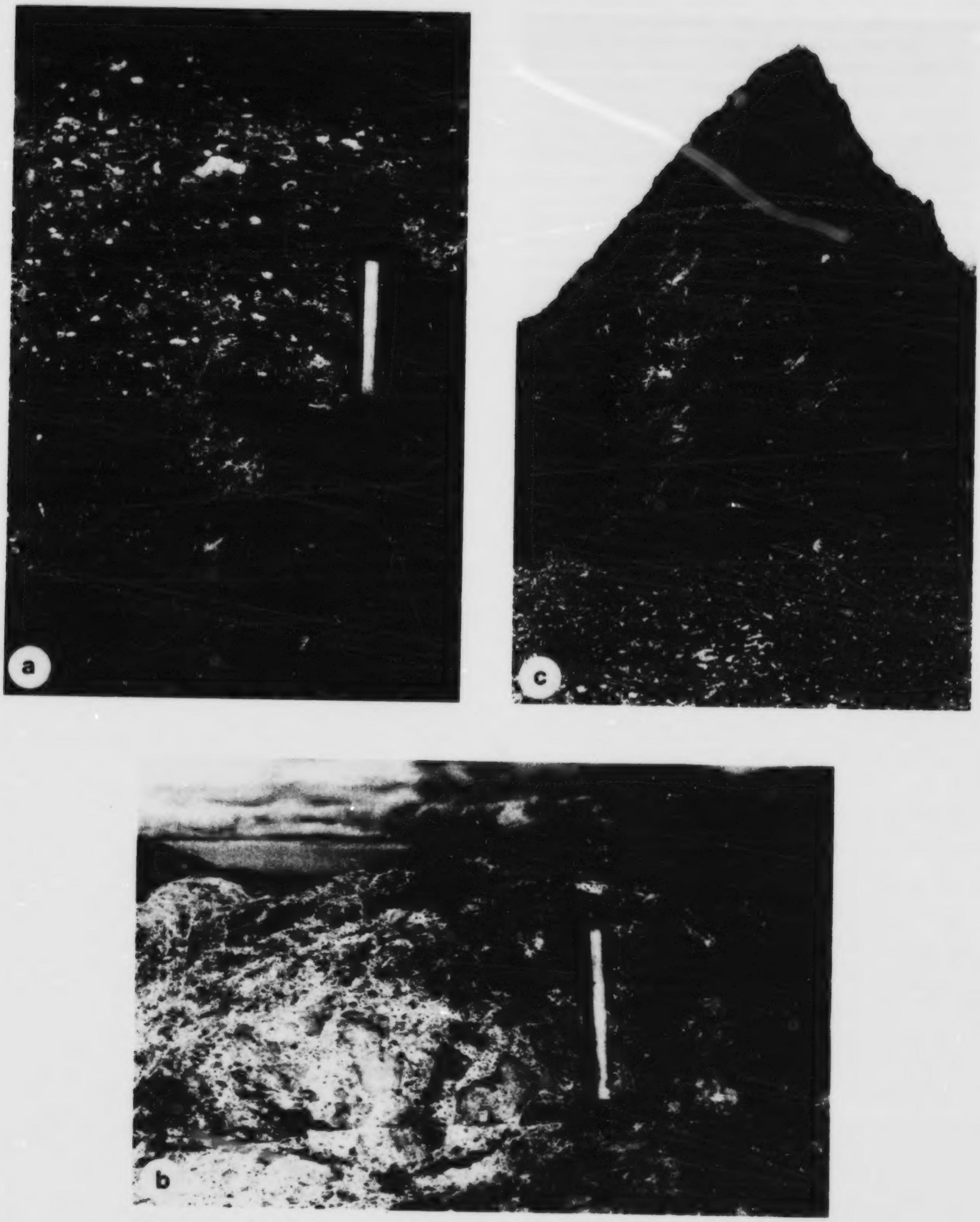

Figure 3. Mid-Miocene sedimentary and volcanic strata, Mount Stapleton area. **A.** Framework-supported conglomerate and trough cross-stratified sandstone. **B.** Volcanic agglomerate located stratigraphically below conglomerates shown in Figure 3A. **C.** Succession of volcanic flows, some of which exhibit columnar jointing.

The volcanic lapilli-block breccias agglomerates which underlie and cover the sedimentary succession (Fig. 1, Unit B) consist of essentially the same clast compositions as the sedimentary strata (Fig. 3B). Clasts up to 20 cm across were noted. The groundmass of these rocks is green with feldspar phenocrysts.

The youngest Tertiary rocks of the region consist mainly of intermediate-composition volcanic flows, as well as flow breccias and minor volcanic-rich conglomerates which range from felsic to mafic in composition (Fig. 1, Unit C). Most flows are aphanitic to medium grained with common phenocrysts of feldspar and mafic minerals. The feldspar phenocrysts are anhedral to euhedral, less than 4 mm long, and generally oriented randomly in the groundmass. Some flows show white and black flow banding in 0.5-12 cm thick bands containing feldspar needles up to 7 mm in length. Locally, the flows have columnar jointing (Fig. 3C).

The relatively minor associated volcanic breccias and conglomerates of more felsic composition consist of grey to bright green matrix with feldspar phenocrysts less than 3 mm in length, together with mafic minerals. Clasts are angular to rounded, generally less than 6 cm across, and consist of white, dark green, and black aphanitic rocks.

The more mafic volcanic conglomerates and breccias have a dark aphanitic groundmass with much the same clast material as the felsic ones. Some mafic flows are dark green to black with anhedral feldspar and mafic phenocrysts, and may have amygdules of quartz or calcite.

STRUCTURAL GEOLOGY

The Cretaceous and Paleogene rocks just south of Yakoun Lake have steeply tilted to overturned bedding. The beds trend mainly northwest without any obvious vergence and are consistent in their orientation with outcrops of these units farther south, along Skidegate Channel and Long Inlet (Haggart et al., 1989; Lewis, 1990), as well as in Jurassic rocks exposed to the northeast (Hesthammer et al., 1989; Indrelid et al., 1990). Thus, the strata just south and west of Yakoun Lake appear to be part of the major northwest-southeast structural trend crossing the islands from Cumshewa Inlet to Skidegate Channel (Thompson, 1988).

The mid-Miocene sedimentary and volcanic succession which overlies the Cretaceous and Paleogene outcrops and is exposed at higher elevations is less deformed than the underlying Cretaceous and Paleogene strata. Within this succession sedimentary bedding and flow contacts in the volcanic rocks generally dip gently east or south.

Faulting in the area is mainly strike-slip in nature with a predominance of sinistral movement. This trend is also found in Jurassic rocks farther northeast (Hesthammer, 1990) and in Cretaceous rocks to the east and north (Indrelid, 1990). The major fault set trends east-northeast, with a minor fault set trending northwest (Fig. 4A). The east-northeast trending faults are pronounced and are readily seen on airphotos. Most observed faults are subvertical.

The major joint pattern in the map area is subparallel to the trend of the major fault set (Fig. 4B). The joints are vertical or dip steeply to the north. A minor joint set trends northwest and dips northeast.

DISCUSSION

The Cretaceous and Paleogene strata which outcrop in the vicinity of the south shore of Yakoun Lake are lithologically similar to other, better exposures of those formations in the Long Inlet area to the south (see Haggart et al., 1989).

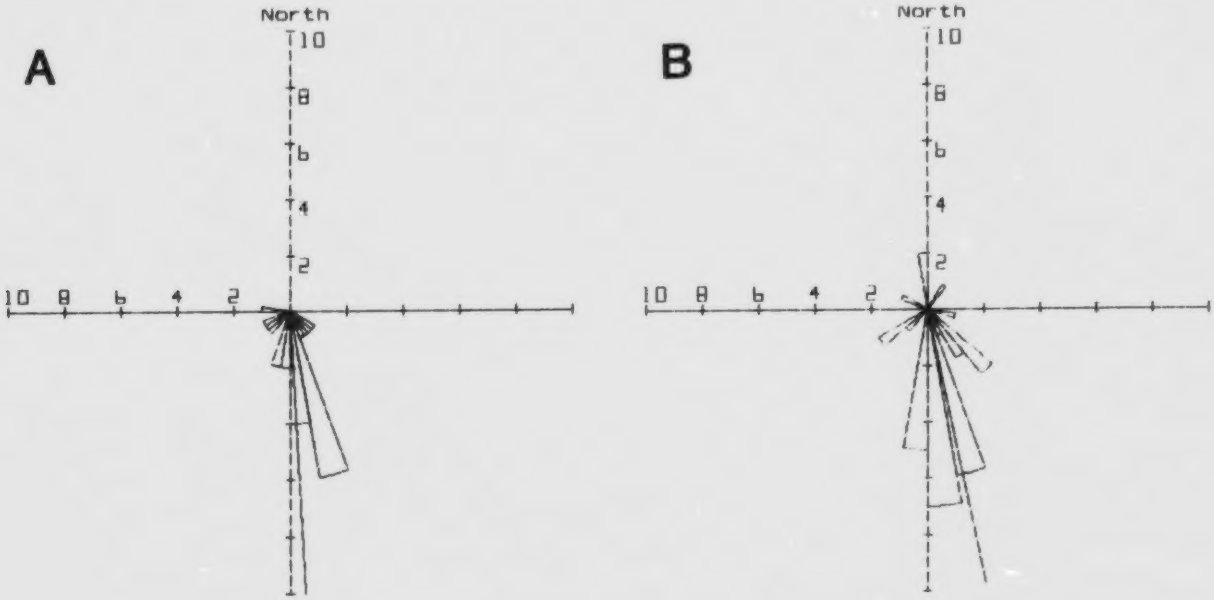

Figure 4. Pole trends of faults and joints in Mount Stapleton area. A. Pole trends for fault orientations, n = 22, mean = 178°. B. Pole trends for joint orientations, n = 32, mean = 168°.

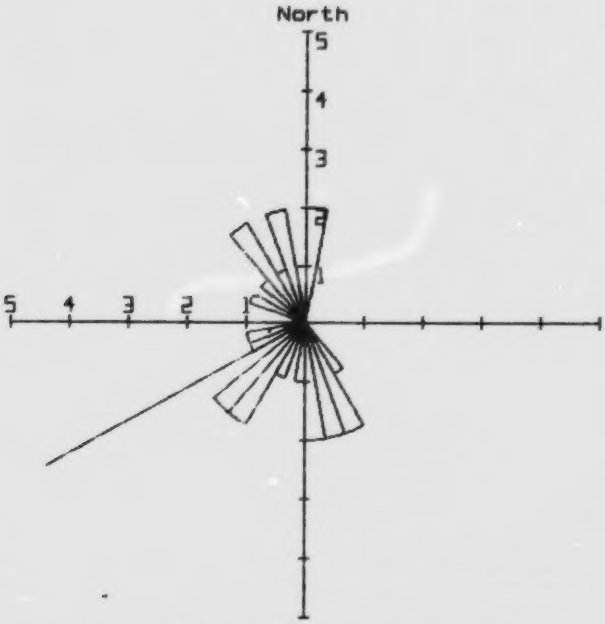

Figure 5. Imbrication trends in mid-Miocene conglomerate, Mount Stapleton area, n = 25, mean = 242°. Measurements from one station.

Most of the rocks in the Mount Stapleton area mapped by Sutherland Brown (1968) as Longarm Formation and Honna Formation are in actuality part of the mid-Miocene sedimentary and volcanic succession. No outcrops of the Cretaceous formations were seen at the higher elevations anywhere in the study area.

The mid-Miocene age of interbedded shales within the lower part of the younger Tertiary sedimentary and volcanic succession indicates that this sequence is, at least in part, equivalent in age to outcrops of the marine to nonmarine Skonun Formation, which is found to the east and northeast of the study area (Sutherland Brown, 1968; Higgs, 1989). No evidence of marine strata was found in the mid-Miocene succession of the Mount Stapleton area. The occurrence of interstratified volcanics within the mid-Miocene sedimentary succession indicates that these volcanics are, at least in part, temporally correlative with the Masset Formation (Hickson, 1989) and supports the suggestion of Cameron and Hamilton (1988) that the Skonun Formation may locally interfinger with volcanics of the Masset Formation.

The massive conglomerates and cross-stratified sandstones of mid-Miocene age are interpreted as deposits of a braided fluvial system established within a volcanic complex. The reverse-graded conglomerates are interpreted as the product of surging debris flows (Nemec and Steel, 1984). Volcanic activity may have resulted in the development of pyroclastic flows which moved downslope and into the fluvial network where they were transformed into surging debris flows (Smith, 1986).

The massive conglomerates exhibit an imbricate fabric, which was analyzed to determine paleocurrent trend. The well indurated nature of the conglomerates hampered measurement of the three dimensional orientation of the a-b plane of clasts. Nevertheless, the vector mean suggests a general west-southwest direction of transport (Fig. 5). The data have a bimodal trend which likely reflects the problems in determining the orientation of the a-b plane.

The difference in deformation between the Cretaceous and Paleogene strata and the younger Tertiary rocks indicates that at least one compressional deformation phase took place prior to deposition of the younger Tertiary succession. Lewis (1990) has shown that a major deformation event affected the Long Inlet region of the Queen Charlotte Islands some time after the Early Eocene to Early Oligocene. This deformation event appears traceable into the Yakoun Lake region but is not reflected in the overlying mid-Miocene succession. Thus, it would appear that the post-Eocene/Oligocene deformation event predates the mid-Miocene.

The abundance of strike-slip faults with mainly sinistral offset indicates that a large amount of total displacement may have taken place (Hesthammer, 1990). The age of this deformational event can be restricted to post-mid-Miocene.

ACKNOWLEDGMENTS

J.W. Haggart wishes to thank M. Neylan for keeping a cool head in tight circumstances. The authors also thank J. Clampett for inspiration in the field.

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Evidence for defining the Triassic-Jurassic boundary at Kennecott Point, Queen Charlotte Islands, British Columbia[1]

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Tipper, H.W. and Carter, E.S., Evidence for defining the Triassic-Jurassic boundary at Kennecott Point, Queen Charlotte Islands, British Columbia; in Current Research, Part F, Geological Survey of Canada Paper 90-1F, p.37-41, 1990.

Abstract

At Kennecott Point in Queen Charlotte Islands, a minor discordance within sediments of the Sandilands Formation, Kunga Group is proposed as the Triassic-Jurassic boundary. Ammonites and radiolarians above the unconformity strongly indicate that the beds are earliest Hettangian in age; ammonites, conodonts, and radiolarians below the unconformity indicate that these beds are probably latest Triassic in age.

Résumé

À pointe Kennecott, dans les îles de la Reine-Charlotte, on propose une faible discordance à l'intérieur des sédiments de la formation de Sandilands, du groupe de Kunga comme limite du Trias et du Jurassique. Des ammonites et des radiolaires, rencontrés au-dessus de la discordance, indiquent fortement que les couches appartiennent à la base de l'Hettangien, et des ammonites, des conodontes et des radiolaires rencontrés au-dessous de la discordance indiquent que ces couches appartiennent propablement au sommet du Trias.

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INTRODUCTION

At Kennecott Point on the northwest coast of Graham Island, Queen Charlotte Islands (Fig. 1) a section of sediments has been studied that crosses the Triassic-Jurassic boundary. The beds are part of the Sandilands Formation of the Kunga Group which is widespread in Queen Charlotte Islands (Cameron and Tipper, 1985; Tipper, 1989). The Sandilands Formation ranges in age from Late Norian (Amoenum zone) to latest Sinemurian or earliest Pliensbachian (the upper boundary is diachronous) (Tipper et al., 1990). The sediments are mainly siltstone, sandstone, and shale with rare thin limy bands and tuffaceous siltstone or tuff. The sediments suggest almost continuous deposition in one basin with alternating bands of siltstone, shale, and sand 0.5-10 cm thick, in places thicker. The general impression is of a well bedded sequence, strongly faulted, generally east-dipping at low angles. The general character is an evenly banded thin-bedded sequence, with rare graded beds, a few tuffs, and uncommon current indicators, ripple marks, or crossbedding.

A section of part of this formation has been reconstructed (Fig. 2). Near the base are faunas that are Upper Norian (Crickmayi zone) and at the top are Lower Hettangian faunas. Between the 70 and 80 m level in an unfossiliferous sandstone interval a fault disrupts the sequence. The amount of loss or repetition of section cannot be determined but is probably small. At the 42 m level a small unconformity is present (Fig. 3 and 4) and this is the only recognizable discordance in the illustrated section (Fig. 2). This unconformity is interpreted as the Triassic-Jurassic boundary, for reasons described below. For convenience, the beds above the unconformity will be referred to as Jurassic beds and those below as Triassic.

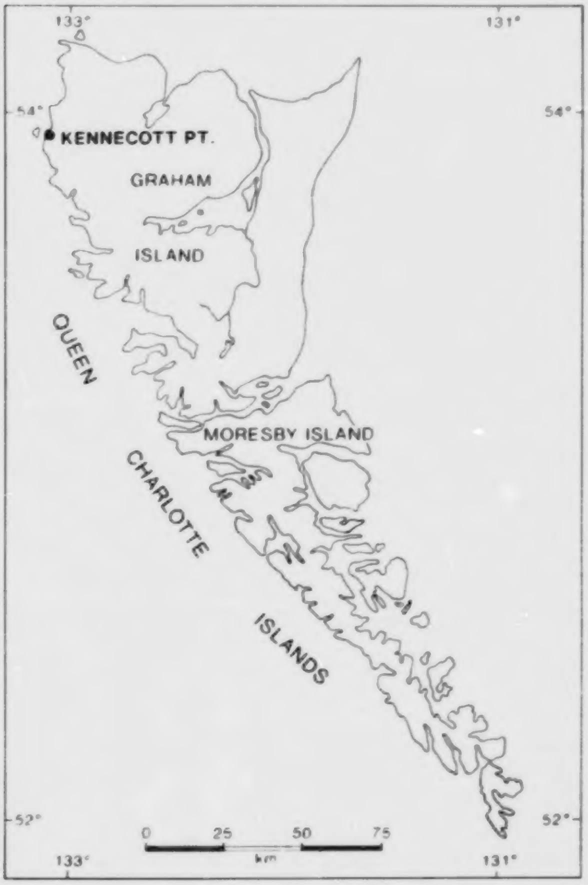

Figure 1. Location of study area.

From this sequence ammonites, radiolarians, and conodonts have been recovered and studied. In addition foraminifers, bivalves, coleoids, crustaceans, crinoids, fish remains, and ichthyosaurs have been collected or noted. Parts of the section are more fossiliferous than others, particularly the finer grained beds, siltstone, and shale. Sandstones in particular have yielded very little.

At the unconformity the Jurassic beds are about 4 m of finely laminated grey to dark grey siltstone, evenly bedded and interbedded with a few green to blue-green bands of sandy siltstone 0.5-2.0 cm thick. Rare grey-blue layers of finely graded tuff are present. These have an uneven undulating base and a somewhat even top; colour varies from darker at the base to light grey at the top. This tuff reaches 2 cm in thickness but generally displays the uneven, almost rippled basal contact. The section as a whole displays a consistent strike and dip. The rock cleaves in large sheets with smooth surfaces along the bedding. The beds near the top of the 4 m section, where ammonites were found, display somewhat oval pits about 1 cm across, a feature that persists for 100 m or more along strike. The section is somewhat resistant.

The Triassic rocks immediately below the unconformity, on the other hand, are a thick section of interbedded, coarse grey to grey-green sandstones and dark grey sandy siltstone. They are coarsely bedded from 3-10 cm thick. Contacts between beds are not sharp but are slightly gradational. The beds fracture at right angles to the bedding into blocks 3-5 cm thick. Whereas the Jurassic rocks are somewhat resistant, the Triassic rocks are recessive. The beds are not obviously tuffaceous.

The contact between the Jurassic and Triassic rocks is marked by a slight unconformity. The bedding in the Jurassic rocks is regular and even right to the contact and in places appears to truncate the Triassic beds below. The Triassic beds are gently undulating (Fig. 3) and in places are at an angle of as much as 5° with the overlying Jurassic beds. It is difficult to determine if this undulatory character of the beds persists to any great depth in the Triassic rocks because of the fracturing of the rock. Also seen at this contact are some prominent irregular blocks of grey sandy limestone up to 1 m across that appear to be exotic and are imbedded in the Triassic sands. The Jurassic siltstones clearly overlie these blocks. No evidence of faulting or shearing was observed at the contact.

This contact possibly could be explained as slumping of rapidly deposited sands followed by an interval of relatively quiet silt deposition. However the faunal evidence above and below this unconformity suggests that it may be of much greater significance. Ammonites and radiolarians above the unconformity strongly suggest a Jurassic age whereas radiolarians, conodonts, and ammonites below indicate a

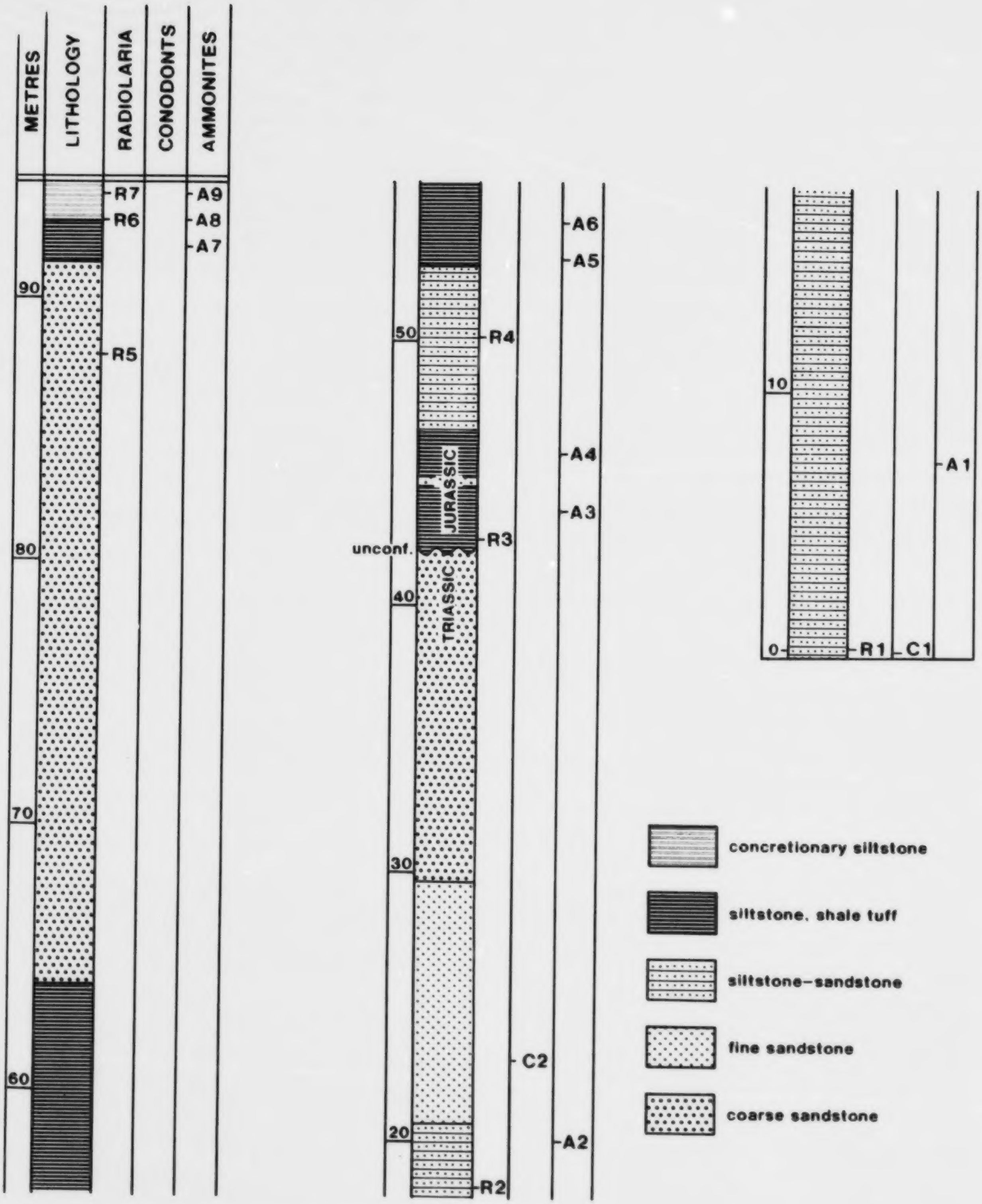
METRES
LITHOLOGY
RADIOLARIA
CONODONTS
AMMONITES
R7
R6
R5
R4
R3
R2
R1
A9
A8
A7
A6
A5
A4
A3
A2
A1
C1
C2
JURASSIC
TRIASSIC
unconf.
0
10
20
30
40
50
60
70
80
90
concretionary siltstone
siltstone, shale tuff
siltstone–sandstone
fine sandstone
coarse sandstone

Figure 2. Reconstructed stratigraphic section and position of faunas above and below the Triassic-Jurassic boundary.

Triassic age, but whether or not it is precisely the Triassic-Jurassic boundary is still a question. A discussion of the faunas with reference to Figure 2 may clarify the degree of certainty suggested.

THE AMMONITES

A few ammonites have been collected at various levels. At localities A1 and A2 (Fig. 2) compressed but identifiable specimens of *Choristoceras* sp. (identification by E.T. Tozer) indicate the Crickmayi zone of the Upper Norian stage of the Triassic. Other faulted sections suggest possible *Choristoceras* specimens may occur slightly higher than A2 but below the Triassic-Jurassic boundary. At levels A3 and A4 highly compressed phylloceratid ammonites resembling *Nevadaphyllites* or *Paradasyceras* occur but cannot be identified with certainty. In Nevada these genera have been identified in the basal beds of the Jurassic Hettangian stage (Guex, 1980). Because of their poor preservation the possibility of a Triassic age cannot be ruled out, but similar ammonites have not been seen at levels A1 and A2 or other known Crickmayi zone localities in Canada. Assemblages at A5 and A6 have poorly preserved forms that may be costate psiloceratids or *Kammerkarites* sp.. Although a definite generic assignment is not possible, the fauna almost certainly is Jurassic in age. At level A7 *Kammerkarites* and *Discamphiceras* were found and at A8 *Fergusonites striatus* occurs. At A9 *Euphyllites, Discamphiceras, Alsatites, Fergusonites*, and *Pleuroacanthites* are well preserved and common; the top of the early Hettangian substage is considered a possible age assignment. The first *Schlotheimia* sp. is found about a metre higher. Thus there is some evidence to suggest that ammonite assemblages A3 to A9 could span the early Hettangian; no ammonites below A3 suggest a Jurassic age.

CONODONTS

At level C1 a species of *Neogondolella* was recovered and, because of faunas such as *Monotis* occurring far below, a Late Triassic age is definite. Because there are no species of *Epigondolella* found at this level or higher, a Crickmayi zone age is probable (M.J. Orchard, personal communication, 1989). At C2 a ramiform specimen was recovered which can only be Upper Triassic Crickmayi zone because of its position above the ammonite *Choristoceras*. The lack of the youngest Triassic conodont, *Misikella*, precludes definitive assignment to a part of the Crickmayi zone. From the C2 level to the proposed boundary 19 m higher, there may be beds that represent the top of the Triassic sequences, either immediately below the boundary or somewhat lower.

RADIOLARIANS

Many generic and specific differences are recognized between radiolarians of latest Triassic and earliest Jurassic age. The radiolarian evidence for a possible Triassic-Jurassic boundary succession at Kennecott Point is shown in Figure 2 as assemblages R1 to R7.

The occurrence of radiolarians in the Sandilands Formation is largely dependent upon lithology. Where micrite concretions are plentiful, well preserved radiolarians are usually abundant; where the beds are more sandy and lack concretions, radiolarians are poor. Many excellent radiolarian collections have been obtained from the base of the formation up to and including the interval with *Choristoceras* (R1). Good radiolarians are found at R4 in beds thought to be earliest Hettangian in age. Higher in the sequence, above a thick sandy interval that is apparently barren of fossils, several collections are present at levels designated R5, R6, and R7.

Three assemblages of Upper Norian radiolarians are recognized in post-*Monotis* strata of the Sandilands Formation (Carter, in press). The middle assemblage (assemblage 2) may be equivalent to the Amoenum zone; the upper assemblage (assemblage 3) is equivalent to the *(Choristoceras)* Crickmayi zone. Many radiolarians common to assemblages 2 and 3 are present in R1 (Fig. 2), but some of these, that is, Gen. nov. C (Carter, in press, Pl. 2, fig. 1) and *Staurosphaera* sp. are more common in the upper assemblage (assemblage 3). *Livarella validas* Yoshida also occurs in R1; according to Yoshida (1986), this species ranges from Lower to Middle Rhaetian in Japan. *Paratriassoastrum* Kozur and Mostler occurs in R2 and *Canoptum* Pessagno is present in both R2 and R3. The canoptid forms

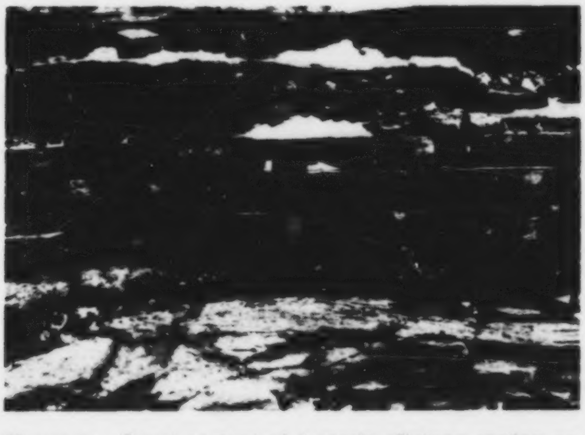

Figure 3. Basal contact of Jurassic siltstone resting on undulating surface of Triassic rocks at Kennecott Point.

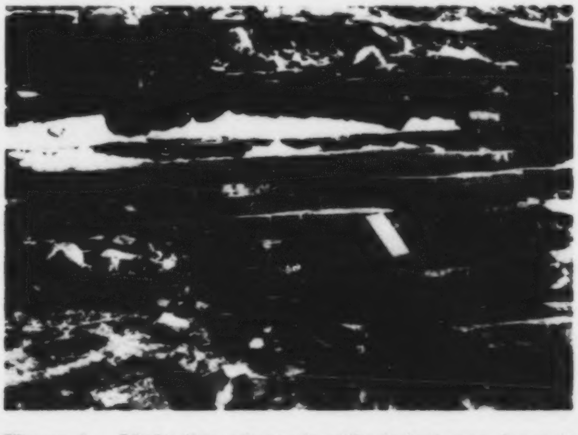

Figure 4. Slight discordance in attitude between Jurassic siltstone and Triassic sandstone-siltstone sequence.

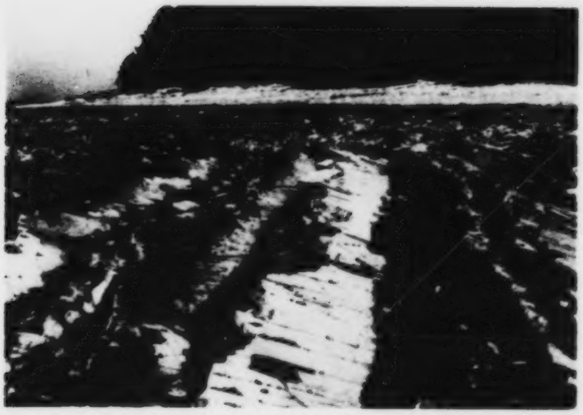

Figure 5. Basal Jurassic siltstones at Kennecott Point.

in R2 are similar to those in R1, whereas the ones in R3 have greater affinity with canoptid species present in R4. R4 contains probable Hettangian forms such as *Bipedis* De Wever, *Relanus* Pessagno and Whalen, *Canoptum merum* Pessagno and Whalen, *C. praeanulatum* Pessagno and Whalen, and *Pantanellium tanuense* Pessagno and Blome. R5 contains a well preserved radiolarian assemblage characterized by *Pantanellium kluense* Pessagno and Blome, *P. tanuense* Pessagno and Blome, *Relanus reefensis* Pessagno and Whalen plus several undescribed forms figured in Tipper et al. (1990, Pl. 8, fig. 2, 3, 6, 7, 18). R6 (equivalent to A8) contains a diverse assemblage that includes all the aforementioned Hettangian taxa plus *Canoptum* cf. *dixoni* Pessagno and Whalen, gen. indet. Z sp. A (Cordey, 1988), and *Homeoparonaella* Baumgartner. R7 (equivalent to A9) contains *Ares* De Wever in addition to the forms mentioned previously.

In summary, R1 is Late Norian in age; R2 is probably Late Norian; R3 is more likely earliest Hettangian; R4 is probably Early Hettangian; and R5, R6 and R7 are Early Hettangian.

CONCLUSIONS

Considering all three faunas together, there is good reason to consider the minor unconformity as the Triassic-Jurassic boundary. Above the unconformity there are no conodonts and the radiolarians and the ammonites are either probably Jurassic or definitely Jurassic. It is highly unlikely that the fauna can be considered as even possibly Triassic. Below the unconformity the faunas are Triassic conodonts, Crickmayi zone ammonites, and radiolarians that are either definitely Triassic or probably Triassic. No fauna below the unconformity is considered possibly Jurassic. However, between levels C2 and R3, a thickness of 19.5 m, a section of mostly coarse sand has no paleontological age control; we prefer a latest Crickmayi zone age, although a Jurassic age for part cannot be ruled out.

Tentatively we have chosen the unconformity as the most logical boundary between the Triassic and Jurassic. The lithostratigraphy indicates an abrupt change in lithology from sands to silts; evidence of an apparent minor discordance and evidence of resumption of volcanism in the Jurassic beds. Faunas strongly suggest that all the beds above the unconformity are Jurassic, and more precisely, basal Hettangian. Below the unconformity the faunas indicate they are Triassic, and specifically the highest faunas are early to mid-Crickmayi zone. The unfossiliferous beds may represent latest Crickmayi zone time. This unconformity represents little or no time gap geologically and possibly this section is essentially uninterrupted at the Triassic-Jurassic boundary. Further work needs to be done to fully substantiate this proposal.

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A preliminary note on the application of magnetostratigraphy to the Triassic-Jurassic boundary strata, Kunga Island, Queen Charlotte Islands, British Columbia

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Carter, E.S. and Galbrun, B., A preliminary note on the application of magnetostratigraphy to the Triassic-Jurassic boundary strata, Kunga Island, Queen Charlotte Islands, British Columbia; in *Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p.43-46, 1990.*

Abstract

One hundred and five, 2.5 cm diameter, oriented cores were obtained from Triassic-Jurassic strata of the Sandilands Formation on Kunga Island in July 1989.

Résumé

Cent cinq carottes orientées, de 2,5 cm de diamètre, ont été prélevées en juillet 1989 dans des couches du Trias et du Jurassique de la formation de Sandilands de l'île Kunga.

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INTRODUCTION

In July 1989, joint magnetostratigraphic-biostratigraphic investigations of Triassic-Jurassic boundary strata on Kunga Island, Queen Charlotte Island were begun. This is a first attempt to apply magnetostratigraphy to the study of a major stage boundary in western Canada. The Kunga Island sections offer a good opportunity to establish the magnetic polarity sequence of Late Triassic-Early Hettangian time.

Radiolarians are the only fauna in uppermost Triassic beds at Kunga Island that have biostratigraphic control. Rare ammonites are present in basal Jurassic beds and co-occurring micrite concretions have recently been sampled for radiolarians, but results are not yet available. The stratigraphic control for any developing magnetozones will be provided by Upper Norian radiolarian assemblages of Carter (in press), radiolarian zones of Pessagno et al. (1987), and other biostratigraphic data available. Magnetostratigraphy has the potential for correlation in unfossiliferous strata where other age control is not available or possible.

During field studies, 105 oriented cores, 2.5 cm in diameter were obtained by Galbrun from two sections. The core sites are distributed throughout both measured sections at sample intervals ranging from 0.3 m to 3.5 m. Both sections were remeasured and resampled for radiolarians by Carter to confirm the radiolarian biostratigraphy.

Stratigraphy

Triassic-Jurassic beds of the Sandilands Formation (Kunga Group) are exposed along a low wave-cut bench and high knoll on the southeast side of Kunga Island (Fig. 1). The slightly overturned beds with near vertical dip strike between 7° and 90°. In 1987, Carter measured two sections at this locality: Section B (52°45''26"N, 131°33'46"W) begins 37 m above the last occurrence of *Monotis* and is 92 m in thickness. Section D (52°41'34"N, 131°33'37"W), about 100 m to the east, is 132 m thick. The beds are primarily dark grey to black, partly laminated siliceous siltstone (5-10 cm thick) (Fig. 2) with minor grey-green tuffaceous silty shale bands up to 5 cm thick, a few prominent calcareous sandstone beds (up to 50 cm thick), and many horizons containing micrite concretions (Fig. 3). The micrite concretions range in diameter from 5-80 cm and have a thickness of 4-15 cm; the smaller concretions commonly contain well preserved radiolarians. In the upper part of Section D, several stacked concretion beds consisting of interbedded sandstone-siltstone layers (Fig. 4) provide a distinctive stratigraphic marker. These beds weather light yellow-brown to dark brown in a nodular pattern informally referred to as the "eyeglass beds".

Section B is entirely Upper Norian (younger than Cordilleranus Zone) and radiolarians are the only biostratigraphically controlled fauna. Section D is Upper Norian

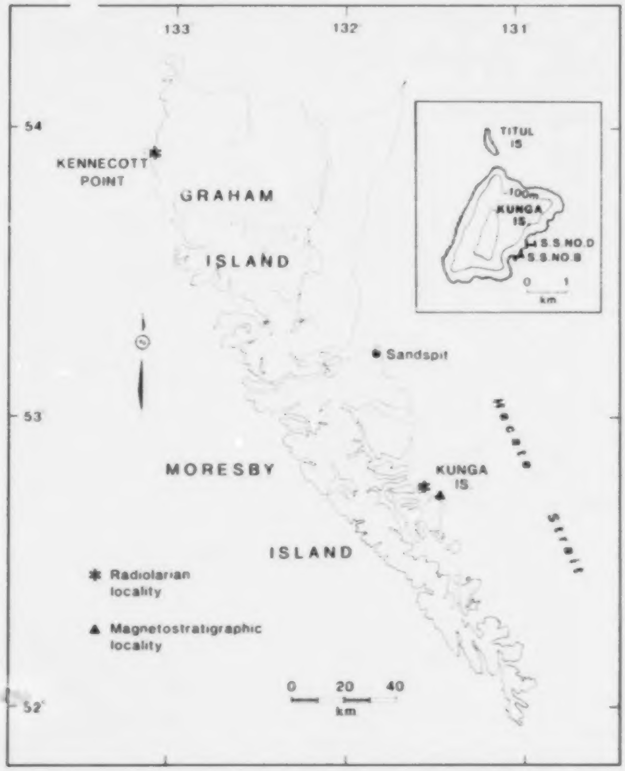

Figure 1. Index map of Queen Charlotte Islands. Inset shows location of stratigraphic sections B and D on the south side of Kunga Island.

and Hettangian; rare conodonts are present in the basal few metres (M.J. Orchard, personal communication, 1988), but well preserved radiolarians occur abundantly throughout most Upper Norian beds. When studied in 1987, the sandy, apparently barren beds in the upper part of Section D were not examined but thought likely to be a continuation of the Triassic. The 1989 field studies now show that ammonites collected from the upper 28 m are Hettangian.

On Kunga Island, the Upper Norian-Hettangian transition is completely exposed over a 23 m interval along the top of a knoll high above the sea. Prominent iron staining is present at several levels just below and within the lowest beds containing Jurassic ammonites, but no break in the sequence is apparent. Radiolarian studies of the Sandilands Formation at this locality on Kunga Island have been in progress since 1987. Magnetostratigraphic analysis correlated to radiolarian assemblages is now being investigated. Given the potential for an important stage boundary at this locality on Kunga Island, the sedimentology and geochemistry of these beds require further study. At Kennecott Point, northern Queen Charlotte Islands, another possible Triassic-Jurassic boundary sequence is under study by Tipper and Carter (Tipper et al., 1990; Tipper and Carter, 1990). These beds are exposed on a low intertidal wave-cut bench and contain radiolarians and rare ammonites of Late Norian to Early Hettangian age.

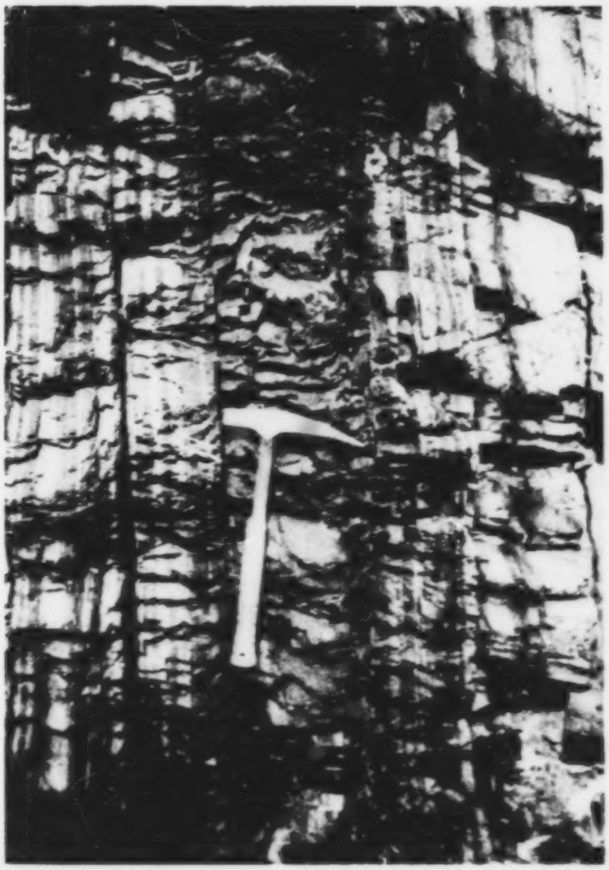

Figure 2. Partly laminated siliceous siltstone beds exposed in the lower part of Section D; Upper Triassic part of Sandilands Formation, south side of Kunga Island.

Magnetostratigraphy

The main objective of the magnetostratigraphic study of the Sandilands Formation is to determine the magnetic polarity sequence of the Late Triassic-Early Hettangian. The geomagnetic polarity time scale of this period is not well known and can only be established by magnetostratigraphic studies on well dated sedimentary sections, given the lack of ocean basins older than Middle Jurassic. There have been only a few magnetostratigraphic studies on Triassic continental sedimentary sections (McIntosh et al., 1985) and it seems that the Norian through Hettangian is a period of predominantly normal polarity with some short reversed polarity zones (e.g. Haq et al., 1987).

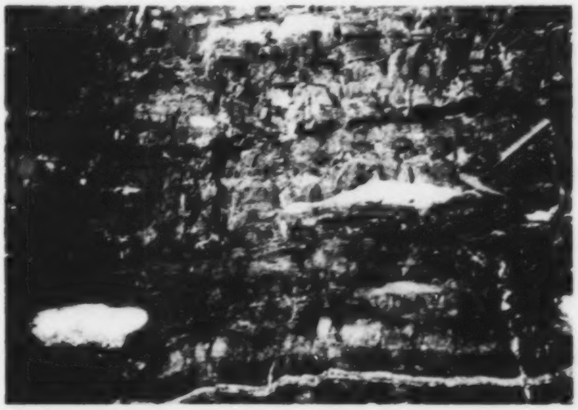

Figure 3. Micrite concretions in bedded siltstone about 28 m above base of Section D; Upper Triassic part of Sandilands Formation, south side of Kunga Island. These concretions commonly contain well preserved radiolarians.

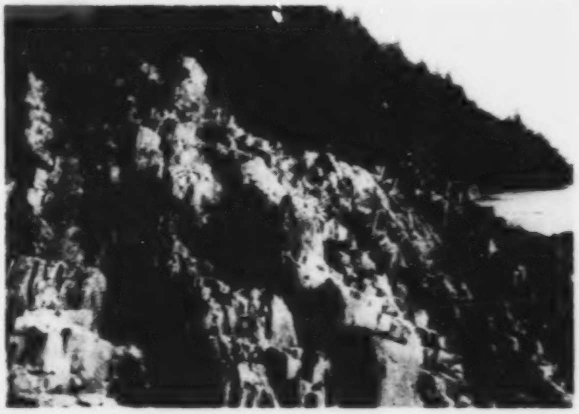

Figure 4. Steeply dipping, slightly overturned beds in upper part of Section D; Lower Jurassic part of Sandilands Formation, south side of Kunga Island. Uppermost level of the distinctive concretionary "eyeglass beds" can be seen left of centre. Thick sandstone bed above is 50 cm thick.

The samples collected on Kunga Island consist of cores drilled in the field and oriented with a magnetic compass. They will be measured with a three-axis RS-01 (LETI/CEA) cryogenic magnetometer and analyzed by the usual paleomagnetic techniques such as thermal and alternating field demagnetization to isolate the primary remanent magnetization.

The Kunga Island sections could be correlated with the sections cored on the Exmouth Plateau (Indian Ocean, northwest Australia) during ODP Leg 122 (Leg 122 Shipboard Scientific Party, 1989). On the Exmouth Plateau the Upper Carnian-Norian sequence is dated by palynofloras and good magnetostratigraphic results were obtained (work in progress by B. Galbrun).

Biostratigraphy

Radiolarians are the main fossil group present in post-*Monotis* beds of the Sandilands Formation at Kennecott Point and Kunga Island. Three preliminary radiolarian assemblages have been established (Carter, in press) and further work is in progress. The lower radiolarian assemblage may possibly be equivalent to the upper part of the *Betraccium deweveri* Subzone (Blome, 1984), the middle assemblage is roughly equivalent to the Amoenum Zone, although no ammonoids to indicate that age have been collected. The upper assemblage correlates with ammonoids from the uppermost Norian Crickmayi Zone. Independent dating for these assemblages has been established from strata at Kennecott Point (Carter, in press; Carter et al., 1989).

Despite an intensive search, no Upper Norian macrofossils have been found in sections B and D on Kunga Island. This may be due to the silicification of the rocks which makes recovery of macrofossils difficult. Hettangian ammonites, found higher in the section, are exposed only on bedding surfaces and are preserved as flattened impressions.

Well dated Hettangian radiolarians are known from Kennecott Point (Tipper et al., 1990; Tipper and Carter, 1990). Collections from Kunga Island (north side) can be dated by detailed comparison with those at Kennecott Point. Of the 14 samples collected in Section D at Kunga Island (south side) in July 1989, many are known to contain abundant, well preserved radiolarians but results are not yet available.

Peril Formation

An additional 19 oriented cores were collected by Galbrun from the Peril Formation (Section A) on the south side of Kunga Island. This Upper Carnian-Lower Norian section is dated by conodonts (M.J. Orchard, personal communication, 1989) and also contains bivalves and radiolarians.

ACKNOWLEDGMENTS

We thank J.W. Haggart and the Queen Charlotte Islands Frontier Geoscience Program for logistical support. We further thank Giselle Jakobs for her patience and expertise in collecting ammonites from some "very barren-looking rock" and Greg Gillstrom for assistance in the field.

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Potential for ammonite biostratigraphy of the Sinemurian part of the Sandilands Formation, Queen Charlotte Islands, British Columbia[1]

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Pálfy, J., McFarlane, R.B., Smith, P.L., and Tipper, H.W., Potential for ammonite biostratigraphy of the Sinemurian part of the Sandilands Formation, Queen Charlotte Islands, British Columbia; in Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 47-50, 1990.

Abstract

Preliminary results from biostratigraphic studies of ammonites from the upper part of the Sandilands Formation demonstrate the presence of a complete Sinemurian section. The successive ammonite assemblages offer stratigraphic control in an otherwise monotonous lithological succession and, on a regional scale, will contribute to the establishment of a standard North American zonation.

Résumé

Des résultats préliminaires provenant d'études biostratigraphiques d'ammonites de la partie supérieure de la formation de Sandilands montrent la présence d'une section complète du Sinémurien. Les assemblages d'ammonites consécutifs offrent un contrôle stratigraphique dans une série lithologique autrement monotone et à échelle régionale, contribueront à l'établissement d'une zonation uniformisée nord-américaine.

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INTRODUCTION

The Sandilands Formation is a several hundred metres thick unit of well bedded dark shale and siltstone interbedded with graded and tuffaceous sandstone, representing the deposition of distal turbidites and lesser air-fall tuffs in a relatively deep marine setting. This unit is widespread in the Queen Charlotte Islands and ranges in age from the Late Norian through the earliest Pliensbachian. Sinemurian ammonites from the Sandilands Formation were first identified by H. Frebold (in Sutherland Brown, 1968) but the first attempt at more refined biostratigraphic subdivision was made by Cameron and Tipper (1985). The main objective of the present work is to establish a local ammonite biostratigraphic scheme that would contribute towards a regional North American zonation for the Sinemurian, similar to the one already completed for the Pliensbachian (Smith et al., 1988).

During the 1989 field, Pálfy collected and measured Sinemurian sections at Kennecott Point on northwest Graham Island, Yakoun River on central Graham Island, and Sewell Inlet-Tasu Sound on Kunga Island (Fig. 1). This report also incorporates recent work on a small quarry in central Graham Island by McFarlane (1988).

BIOSTRATIGRAPHY

The starting point for the present studies has been the faunal sequence observed by Cameron and Tipper (1985), from oldest to youngest:

(7) *Entolium balteatum* Crickmay
(6) *Paltechioceras (=Melanhippites)* sp.
(5) oxynoticeratids and *Paltechioceras* sp.
(4) *Asteroceras* sp.
(3) *Arnioceras* sp.
(2) *Arnioceras (=Arniotites)* sp.
(1) *Badouxia* sp.

These faunal levels are referred to by number in the following discussion.

Kennecott Point, northwest Graham Island

Rocks of the Sandilands Formation directly overlying the Triassic Peril Formation are extensively exposed on a wave-cut platform at Kennecott Point. Structural complications include several sets of strike-slip and normal faults resulting in stratigraphic repetition. The locality is one of the most fossiliferous known from the Sandilands Formation and an abundant collection has been obtained in addition to that made in 1988 (Tipper, 1989). The well documented Hettangian/Sinemurian transition is of great international interest, because this controversial boundary is the subject of debate (Guex and Taylor, 1976; Bloos, 1983; Taylor, 1986). At present we tentatively accept the first occurrence of *Badouxia canadensis* Frebold as the indicator of the basal Sinemurian. Levels 1 and 2 (Cameron and Tipper, 1985) are represented at Kennecott Point. Field observations indicate that *Badouxia columbiae* Frebold ranges stratigraphically higher than *Badouxia canadensis*. *Metophioceras rursicostatum* Frebold is another common element of the assemblage, along with less frequent *Angulaticeras* sp. and *Eolytoceras* sp..

A separate faunal level represented by *Coroniceras ?* sp. has been recognized between the *Badouxia* fauna and the first occurrence of *Arnioceras*, suggesting the potential for further subdivision. The *Arnioceras* beds are faulted against or uncomformably overlain by Tertiary volcanics of the Masset Formation.

Central Graham Island

In central Graham Island the Sandilands Formation is exposed in river and creek beds and in a number of quarries and roadcuts. The section in a small quarry dubbed the "Flagstone quarry" (Fig. 1) was recently studied in detail by McFarlane (1988). Faunas obtained from the section of about 30 m indicated Late Sinemurian age, including levels 4 to 6 of Cameron and Tipper (1985) (Fig. 2). The lowest assemblage is characterized by *Asteroceras*, *Arctoasteroceras* and *Epophioceras* correlative with the northwest European Obtusum Zone. The next higher assemblage consists of co-occurring species of *Oxynoticeras* and *Paltechioceras*. In the topmost 10 m of the section *Paltechioceras* is the only ammonite genus found and is represented by *P. harbledownense* (Crickmay), *P. rothpletzi* (Bose) and *P. boehmi* (Hug). These two assemblages are considered to be equivalent to the upper part of the Upper Sinemurian.

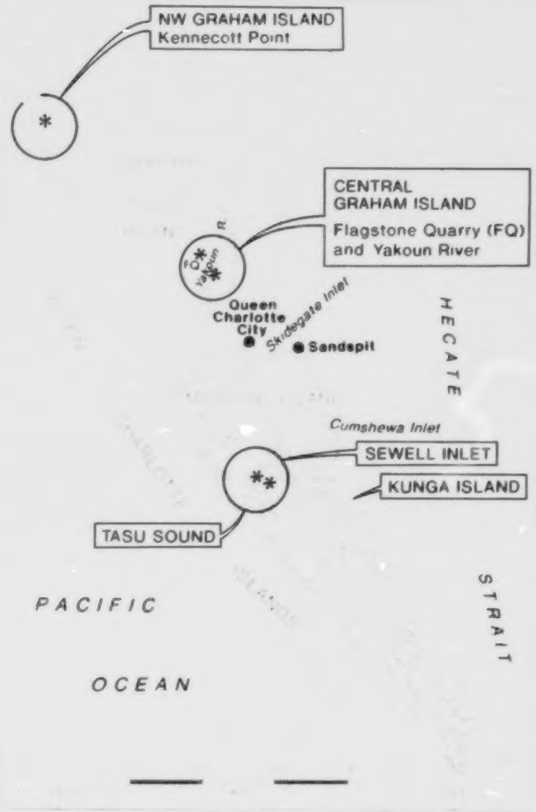

Figure 1 Location of stratigraphic sections, Sinemurian part of the Sandilands Formation, Queen Charlotte Islands.

A new and important section has been discovered along 600 m of the Yakoun River (Fig. 1) as a result of the unusually low water level in the summer of 1989. The Sandilands and overlying Ghost Creek formations are exposed in a structurally uncomplicated sequence. From the Sinemurian part of the main section at the west bank, 47 successive collections were obtained and an additional 25 collections represent the Lower Pliensbachian. The faunal levels 3 to 7 of Cameron and Tipper (1985) were recognized. The overlap of ranges of *Arnioceras* and *Asteroceras* known from Europe has been recorded here. Most of the *Asteroceras* beds are faulted out of the main section but are present along strike farther upstream. The oxynoticeratids are relatively abundant in a narrow interval and the presence of a succession of different *Paltechioceras* species allows subdivision. In the beds characterized by the extremely abundant bivalve *Entolium balteatum*, ammonites are uncommon with the notable exception of *Crucilobiceras?* sp., suggesting correlation with the Raricostatum Zone. Close to the Sinemurian/Pliensbachian boundary, beds with monospecific *Juraphyllites* sp. fauna occur. The highest Sinemurian beds contain *Crucilobiceras?* sp.

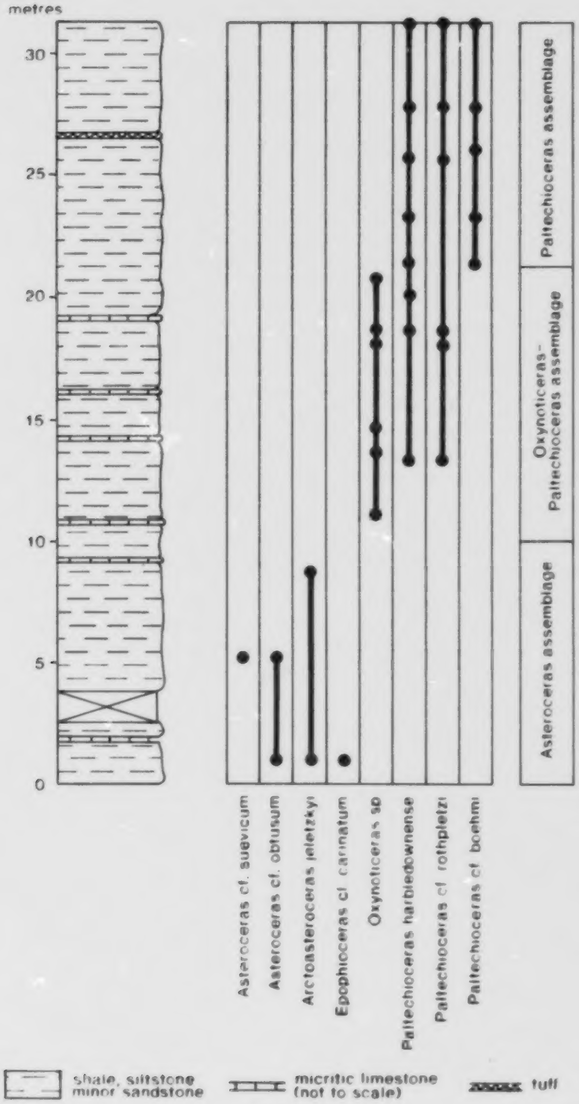

Figure 2. Stratigraphic section of the Flagstone quarry with ranges of ammonites and faunal assemblages.

The Sandilands Formation passes into the Ghost Creek Formation within a 10 m transitional interval marked by gradually increasing amounts of soft shale and a decrease of fine laminations. This facies change is observed within the *Entolium balteatum* beds, nearly 30 m below the incoming of lowest Pliensbachian ammonites.

Sewell Inlet – Tasu Sound area

In this extensively logged area several quarries and roadcuts provide exposures of the Sandilands Formation. One quarry on logging road W-160 exposes a 10 m section of alternating siltstone, shale, and sandstone capped by a sill. This locality yielded a fauna consisting of relatively well preserved specimens of different species of *Arnioceras*, tentatively assigned to level 3 of Cameron and Tipper (1985).

Another quarry along the logging road W-100 exposes a 20 m section of the Sandilands Formation. Different species of *Paltechioceras* range throughout indicating level 6 (Cameron and Tipper, 1985). One of the highest collections yielded *Juraphyllites* sp. suggesting the uppermost Sinemurian, although no *Entolium balteatum* was found.

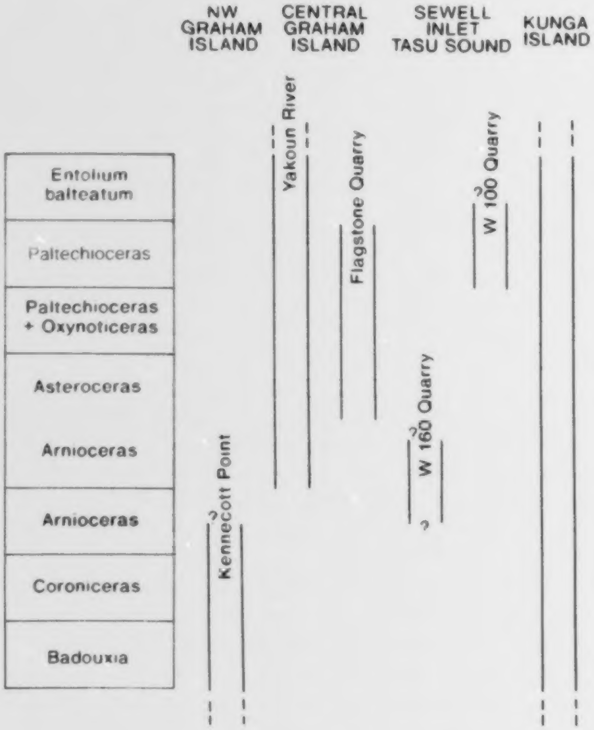

Figure 3. Biostratigraphy and correlation of stratigraphic sections, Sinemurian of the Queen Charlotte Islands. Informal faunal assemblages are modified from Cameron and Tipper (1985).

Kunga Island

Long coastal sections of the Sandilands Formation on the northeast and southeast side of Kunga Island were first measured by Sutherland Brown (1968). However, the first attempt to systematically recover ammonites was made during the 1989 field season. Sinemurian rocks here are moderately fossiliferous, yielding rather poorly preserved ammonites. The sections are affected by the emplacement of several dykes and by numerous faults and folds, making the biostratigraphic work more difficult. In spite of these disturbances, all seven faunal levels of Cameron and Tipper (1985) were recognized. Kunga Island therefore is the only known locality on the Queen Charlotte Islands with a complete, although broken, Sinemurian section. The section spans both the Hettangian/Sinemurian and the Sinemurian/Pliensbachian boundaries with apparent continuity. The lowermost Sinemurian assemblage consists of sparse *Badouxia* sp. and *Metophioceras* sp.. After Kennecott Point, this is the second known occurrence of this assemblage from the Queen Charlotte Islands. The uppermost Sinemurian is represented by beds with *Entolium balteatum* and occurrence of *Juraphyllites* sp. and *Crucilobiceras ?* sp.. The Sandilands Formation seems to persist through the lowermost Pliensbachian and displays a gradational transition into the Ghost Creek Formation. There is a marked diachronism, because the contact of these formations appears to become older toward the north, for example in the Yakoun River section (for further discussion see Smith et al., 1990).

CONCLUSIONS

Through extensive collections from the Sinemurian part of the Sandilands Formation, the schematic biostratigraphic framework of Cameron and Tipper (1985) has been shown to be valid and directions for its refinement have been outlined. Figure 3 shows the correlation of the studied sections.

Sections at Kunga Island serve as general reference sections spanning the whole Sinemurian showing its lower and upper boundaries. Problems such as poor preservation, contact metamorphism, and structural complexities may not allow the elaboration of more detailed biostratigraphy here, however

Kennecott Point is the most important locality with respect to the lowermost Sinemurian and the Hettangian/Sinemurian boundary. Within the *Badouxia-Metophioceras* assemblage, further subdivision will be possible based on the ranges of different species. Between the *Badouxia* and *Arnioceras* faunas a distinct level occurs characterized by *Coroniceras ?* sp.

Arnioceras faunas from the Sewell Inlet-Tasu Sound area might potentially contribute toward a better understanding of these assemblages on the basis of the ranges of different species of *Arnioceras*.

From the *Arnioceras* level upward, the Yakoun River section provides the most comprehensive data. The overlap of ranges of *Arnioceras* and *Asteroceras* is clear. The highest faunal assemblage, formerly characterized only by *Entolium balteatum*, has now yielded ammonites such as *Crucilobiceras ?* sp. and *Juraphyllites* sp., promising a more efficient correlation. The section displays a well documented Sinemurian/Pliensbachian transition.

From the *Asteroceras* through the *Paltechioceras* level, the Flagstone quarry provides an excellent auxiliary reference section featuring a succession of an *Asteroceras-Arctoasteroceras* assemblage followed by an *Oxynoticeras-Paltechioceras* assemblage which is in turn replaced by a fauna containing exclusively species of *Paltechioceras*.

ACKNOWLEDGMENTS

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Lower Jurassic biostratigraphy of the Fannin and Ghost Creek formations, Kunga Island, British Columbia[1]

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Smith, P.L., Tipper, H.W., and Pálfy, J., Lower Jurassic biostratigraphy of the Fannin and Ghost Creek formations, Kunga Island, British Columbia; in *Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 51-54, 1990.*

Abstract

A new stratigraphic section spanning the boundary between the Kunga and Maude groups was found in northeastern Kunga Island. The upper Sandilands Formation has yielded an upper Sinemurian ammonite and bivalve fauna. The Ghost Creek and Fannin formations have yielded lower Pliensbachian ammonites of the Whiteavesi and Freboldi zones. In this, the most southerly occurrence of the lower Maude Group, the light-coloured tuff and lithic sandstone laminations that normally characterize the Sandilands Formation, persists spasmodically to higher stratigraphic levels than seen elsewhere.

Résumé

On a trouvé dans le nord-est de l'île Kunga une nouvelle coupe stratigraphique qui chevauche la limite des groupes de Kunga et de Maude. La partie supérieure de la formation de Sandilands a fourni une faune d'ammonites et de bivalves du Sinémurien supérieur. Les formations de Ghost Creek et de Fannin ont fourni des ammonites du Pliensbachien inférieur des zones de Whiteavesi et de Freboldi. Dans cette coupe, la manifestation la plus méridionale de la partie inférieure du groupe de Maude, constituée de lits fins de tuf clair et de grès lithique, qui caractérisent normalement la formation de Sandilands, se retrouvent d'une façon irrégulière dans des niveaux stratigraphiques plus élevés ailleurs.

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INTRODUCTION

Biostratigraphic studies of the Lower Jurassic formations of the Queen Charlotte Islands deal with the upper Kunga Group and entire Maude Group. The goal is to integrate macrofossil and microfossil data to provide a biochronology of general value. The Queen Charlotte Islands biostratigraphic sequences promise to provide new standards of reference to which other North American faunal successions can be compared. Some of these data have been published (Smith et al., 1988; Carter et al., 1988; Tipper et al., 1990; Smith and Tipper, in press) while other work is in progress.

Shoreline exposures of the Kunga Group in northeastern Kunga Island (Fig. 1) are tectonically disrupted and in places hornfelsed by dykes. Upper Sinemurian ammonite faunas dominated by species of *Paltechioceras* have been known here since the mapping of Sutherland Brown (1968). Detailed work in the summer of 1989 aimed at expanding our understanding of the Sinemurian faunas of the Queen Charlotte Islands revealed a new and fairly continuous stratigraphic section across the Kunga-Maude Group boundary in which a sequence of three faunal assemblages is recognized stratigraphically overlying the *Paltechioceras* beds (Fig. 2).

AMMONITE BIOSTRATIGRAPHY

The lowest assemblage consists of *Juraphyllites* sp. and *Crucilobiceras ?* sp., together with the thin-shelled bivalve *Entolium balteatum* Crickmay which crowds some bedding surfaces (Pálfy et al., 1990). Such an association over a narrow stratigraphic interval has been recognized in Cumshewa Inlet, Skidegate Inlet, and central Graham Island where it is provisionally interpreted to represent the uppermost Sinemurian (Cameron and Tipper, 1985; Tipper et al., 1990). The almost 35 m of Sandilands Formation above this lowest assemblage has yielded sporadic, unidentifiable fossils.

The middle assemblage comprises a moderately well preserved eoderoceratid and acanthopleuroceratid fauna characteristic of the Whiteavesi Zone of the lower Pliensbachian (Smith et al., 1988). The most common species include *Acanthopleuroceras whiteavesi* Smith and Tipper, *A.* aff. *stahli* (Oppel), *Tropidoceras actaeon* d'Orbigny, and *Metaderoceras evolutum* (Fucini).

The highest assemblage includes *Dubariceras freboldi* Dommergues, Mouterde and Rivas; *Aveyroniceras italicum* (Meneghini); and *Metaderoceras* aff. *muticum* (d'Orbigny), characteristic of the Freboldi Zone, the highest zone of the lower Pliensbachian. A 15 m interval yielding unidentifiable ammonites separates the middle and upper assemblages.

LITHOSTRATIGRAPHY

In the type areas of the Sandilands and Ghost Creek formations in Skidegate Inlet, the contact between the formations is conformable and abruptly gradational. The contact is drawn at the incoming of thick, dark shale beds, which coincides roughly with the Sinemurian-Pliensbachian boundary (Cameron and Tipper, 1985). Diachronism is suggested by a report of a lowest Pliensbachian (Imlayi Zone) ammonite in the upper Sandilands Formation of Huxley Island, some 40 km south southeast of Kunga Island (Tipper et al., 1990).

Diachronism is also suggested by the Kunga Island section in that the highest locality yielding an uppermost Sinemurian fauna is almost 35 m below the upper contact of the Sandilands Formation. This interval could represent, in whole or in part, the Imlayi Zone of the lowest Pliensbachian, although this has not been proven. The upper contact of the Sandilands Formation is less abrupt and more difficult to draw here than in exposures to the north. Light-coloured tuff and lithic sandstone laminations that are normally characteristic of the Sandilands Formation persist spasmodically to levels within the Ghost Creek Formation that yield middle Lower Pliensbachian (Whiteavesi Zone) fossils.

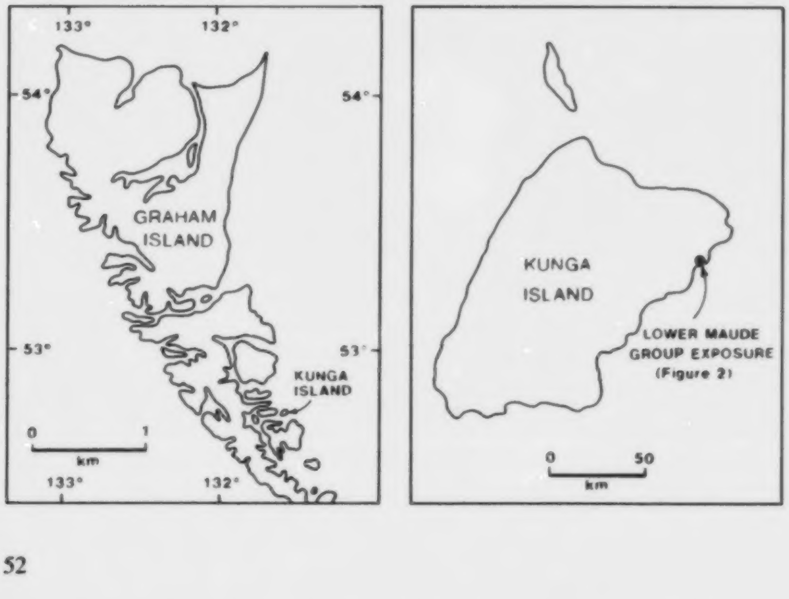
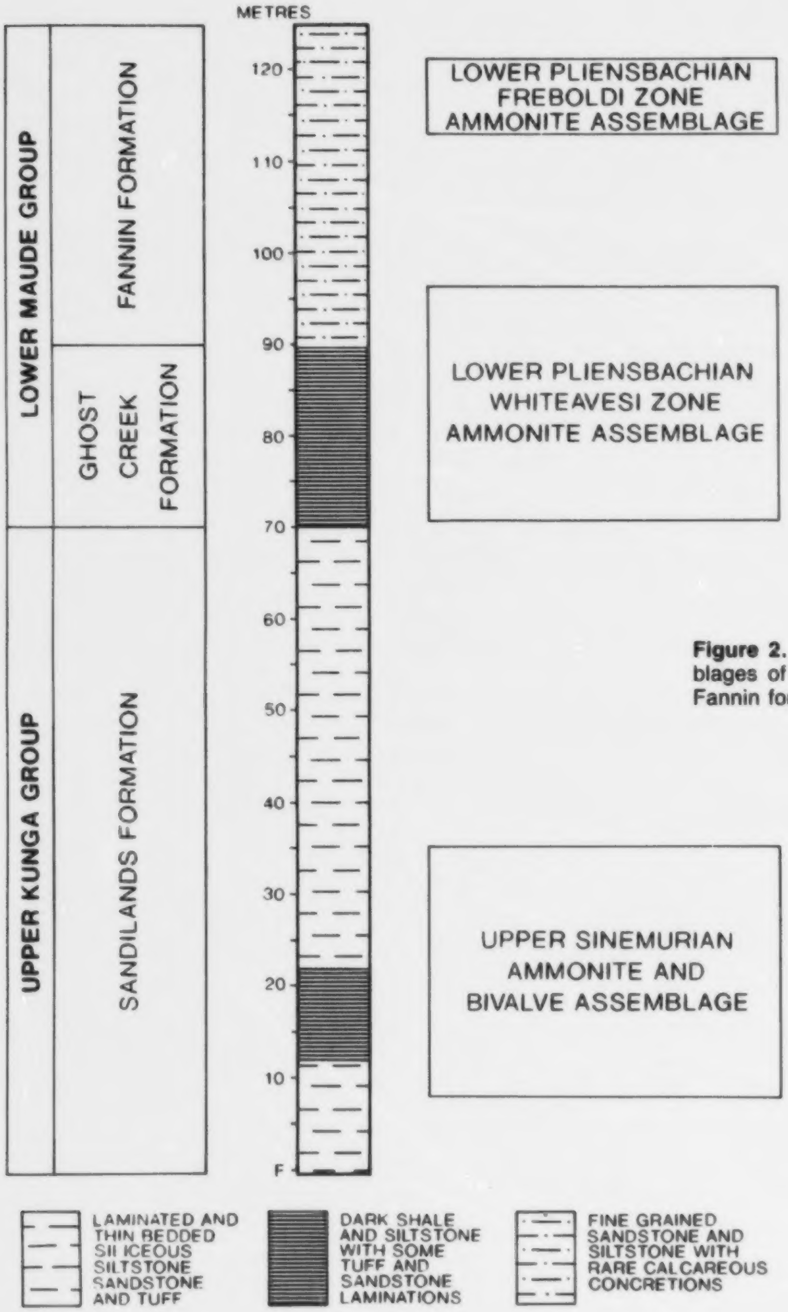


Figure 1. Location of the Kunga Island stratigraphic section.

The upper beds of the Kunga Island section are assigned to the basal Fannin Formation as redefined by Tipper et al. (1990). They consist of alternating sandstones and siltstones that contrast with exposures of the basal Fannin Formation in the type area by being more thinly bedded, less resistant, and in not containing limestone lenses.

CONCLUSIONS

The discovery of this new section significantly expands the known distribution of the lower Maude Group and contributes to our database on Sinemurian and Pliensbachian ammonite biostratigraphy. Lateral variations in facies made evident by the temporal framework provided by the ammonite biochronology point to the need for detailed studies of the sedimentology of the upper Kunga and Maude groups if a full understanding of the Jurassic history of the Queen Charlotte basin is to be achieved. Preliminary observations presented here and elsewhere suggest a southerly volcanic source, perhaps the Bonanza volcanics of Vancouver Island, which are known to contain Sinemurian fossils but whose precise age range is not known.


METRES
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UPPER KUNGA GROUP
SANDILANDS FORMATION
LOWER PLIENSBACHIAN FREBOLDI ZONE AMMONITE ASSEMBLAGE
LOWER PLIENSBACHIAN WHITEAVESI ZONE AMMONITE ASSEMBLAGE
UPPER SINEMURIAN AMMONITE AND BIVALVE ASSEMBLAGE
LAMINATED AND THIN BEDDED SILICEOUS SILTSTONE SANDSTONE AND TUFF
DARK SHALE AND SILTSTONE WITH SOME TUFF AND SANDSTONE LAMINATIONS
FINE GRAINED SANDSTONE AND SILTSTONE WITH RARE CALCAREOUS CONCRETIONS

Figure 2. Stratigraphic section and faunal assemblages of the upper Sandilands, Ghost Creek, and Fannin formations, northeastern Kunga Island.

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We gratefully acknowledge the support of the Frontier Geoscience Program and the Natural Science and Engineering Research Council of Canada. Giselle Jakobs assisted us in the field.

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Preliminary report on the magnetostratigraphy of the Toarcian (Lower Jurassic) strata in the Queen Charlotte Islands, British Columbia[1]

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Cordilleran Division, Vancouver

Jakobs, G.K. and Galbrun, B., Preliminary report on the magnetostratigraphy of the Toarcian (Lower Jurassic) strata in the Queen Charlotte Islands, British Columbia; in *Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 55-56, 1990.*

Abstract

The Toarcian (Lower Jurassic) in the Queen Charlotte Islands is represented by three formations spanning the Upper Pliensbachian to Lower Aalenian. The Fannin Formation, a calcareous sandstone, is Late Pliensbachian to Early Toarcian. The Whiteaves Formation, a silty shale with numerous concretionary horizons, is Early to Late Toarcian in age. The Phantom Creek Formation, a hard, partly calcareous sandstone, is Late Toarcian to Early Aalenian in age. Magnetostratigraphic cores were sampled at approximately 20 cm intervals in the Fannin Formation, at approximately 3 m intervals in the Whiteaves Formation and at approximately 1 m intervals in the Phantom Creek Formation. Correlation of the European magnetostratigraphic scale with the North American and eventually South American scales will provide the framework for a global magnetostratigraphic scale for the Toarcian.

Résumé

Le Toarcien (Jurassique inférieur) des îles de la Reine-Charlotte est représenté par trois formations allant du Pliensbachien supérieur à l'Aalénien inférieur. La formation de Fannin, constituée d'un grès calcaire, a un âge allant du Pliensbachien supérieur au Toarcien inférieur. La formation de Whiteaves, constituée d'un schiste argileux silteux où l'on trouve de nombreux horizons concrétionnaires, a un âge allant du Toarcien inférieur au Toarcien supérieur. La formation de Phantom Creek, constituée d'un grès dur calcarifère, a un âge allant du Toarcien supérieur à l'Aalénien inférieur. On a prélevé des carottes magnétostratigraphiques tous les 20 cm environ dans la formation de Fannin, tous les 3 m environ dans la formation de Whiteaves et tous les mètres environ dans la formation de Phantom Creek. La corrélation de l'échelle magnétostratigraphique de l'Europe avec celle de l'Amérique du Nord et éventuellement celle de l'Amérique du Sud, fournira le cadre d'une échelle magnétostratigraphique mondiale pour le Toarcien.

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A magnetotstratigraphic study of the Toarcian strata of the Queen Charlotte Islands was begun with a week sampling three sections that, when combined, span the entire Toarcian. Cores, 10-15 cm long and 2.5 cm diameter, were taken using standard paleomagnetic methods.

Three formations represent the Toarcian in the Queen Charlotte Islands: the Fannin, Whiteaves, and Phantom Creek formations. The Fannin Formation is Late Pliensbachian to Early Toarcian in age and is composed primarily of a calcareous sandstone. The section at Whiteaves Bay (Section 7 of Cameron and Tipper, 1985) on the south shore of Skidegate Inlet, represents the only known exposure of the Fannin Formation that is of Toarcian age. Cores were taken from the Fannin Formation at roughly 20 cm intervals (26 samples over 7 m), beginning in beds that are latest Pliensbachian in age and ending at the Fannin Formation/Whiteaves Formation contact.

The Whiteaves Formation ranges in age from Early to Late Toarcian and is a greenish grey, fragmented, silty shale that is unsuitable for coring. It contains numerous concretionary horizons and a number of sandstone beds which are more coherent than the shale and yield good cores. The Whiteaves Formation at the Whiteaves Bay section was not cored due to the scarcity of concretionary horizons and the lack of a good ammonite fauna. The main section on the Yakoun River (Section 11 of Cameron and Tipper, 1985) contains numerous concretionary horizons and samples were cored at about 2-4 m intervals (22 samples over 60 m).

The Phantom Creek Formation ranges in age from Late Toarcian to Early Aalenian. It is a greenish, medium grained sandstone that yields good cores and was sampled at two sections. The main section on Yakoun River (Section 11 of Cameron and Tipper, 1985) was sampled from the top of a covered interval to the uppermost part of the formation, which is Aalenian in age, at roughly 1 m intervals (9 samples over 10 m). The type section of the Phantom Creek Formation (Section 12 of Cameron and Tipper, 1985) was sampled beginning at the Whiteaves Formation/Phantom Creek Formation contact, at approximately one metre intervals (24 samples over 22 m), and ending in the Aalenian part of the Phantom Creek Formation (Jakobs, 1990).

The ammonite zonation being prepared by Jakobs will serve as a framework for the magnetostratigraphy. Galbrun has been involved in numerous studies of the magnetostratigraphy of the Toarcian in localities throughout Europe (for example, Galbrun et al., 1988 a, b, 1989). By widening the scope of the work to include North American and eventually South American localities, Galbrun hopes to produce a global magnetostratigraphic scale for the Toarcian. Such a scale could prove immensely useful for the global correlation of Toarcian stratigraphic sections, since magnetic reversals are worldwide and virtually instantaneous.

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A discussion of the Phantom Creek Formation of the Maude Group, Queen Charlotte Islands, British Columbia[1]

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Jakobs, G.K., A discussion of the Phantom Creek Formation of the Maude Group, Queen Charlotte Islands, British Columbia; in Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 57-60, 1990.

Abstract

Reinterpretation of the type section of the Phantom Creek Formation indicates that the lower 'coquinoid sandstone member' is late Upper Toarcian in age and that the upper 'belemnite sandstone member' is Early Aalenian in age. The hiatus separating the two members is greatest at Louise and Maude islands and decreases to the north in Central Graham Island. The 'paleosoil' on Maude Island, described by previous workers, is the alteration product of a concretionary bed and several similar bodies were found throughout the section.

Résumé

La réinterprétation de la coupe type de la formation de Phantom Creek indique que le membre inférieur de grès lumachellique est de la fin du Toarcien supérieur et que le membre supérieur de grès bélemnites date de l'Aalénien inférieur. La lacune séparant les deux membres atteint son maximum dans les îles Louise et Maude et décroît vers le nord dans la partie centrale de l'île Graham. Le paléosol qui se trouve sur l'île Maude, décrit déjà par d'autres chercheurs, est le produit d'altération d'un lit concrétionné et l'on trouve plusieurs formations un peu partout dans cette coupe.

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INTRODUCTION

The Phantom Creek Formation, defined by Cameron and Tipper (1985), is the uppermost component of the Maude Group. It occurs primarily in central Graham Island, except for one outcrop on Maude Island in Skidegate Inlet and one on 'Skedans Rock' off the east coast of Louise Island (Fig. 1). It ranges in age from latest Toarcian to Early Aalenian.

The Phantom Creek Formation is a grey to buff weathering, medium grained, greenish sandstone with several layers of generally unfossiliferous concretions about 1 m in diameter. The formation can be subdivided into two members with an hiatus of variable duration separating the two. The lower member, referred to as the 'coquinoid sandstone member by Cameron and Tipper, is composed of fossiliferous, well bedded, hard sandstones with thin interbeds of a friable, possibly tuffaceous, sand. The upper member, referred to as the 'belemnite sandstone member' by Cameron and Tipper, is a sequence of massive, poorly bedded, greenish sandstones with common spheroidal weathering. Ammonites are rare and most of the fauna is composed of belemnites and some bivalves. In central Graham Island at sections 11 and 12 (all section numbers refer to Cameron and Tipper, 1985) the hiatus is brief or absent. Sections 13 and 14 are much thinner and appear to lack the uppermost beds of the coquinoid sandstone member with most of the formation being Aalenian in age. On Maude Island (Section 4) and at Skedans Rock the coquinoid sandstone member is absent and the belemnite sandstone member rests directly on the underlying Whiteaves Formation.

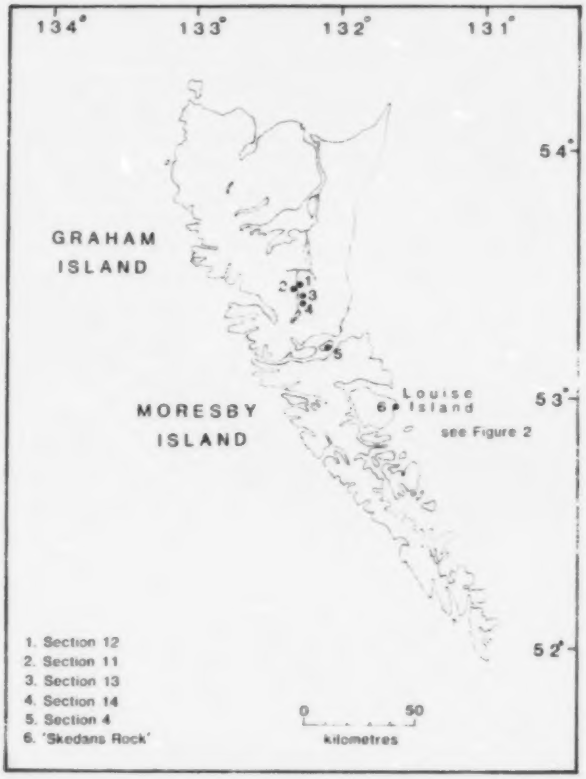

Figure 1. Main Phantom Creek Formation outcrops in the Queen Charlotte Islands.

The Phantom Creek Formation is overlain by the tuffaceous siltstones and shales of the Lower Bajocian Graham Island Formation (Yakoun Group). An unconformity separates the two formations; Late Aalenian and Early Bajocian faunas are absent (Cameron and Tipper, 1985). The contact is distinct but is only observed at sections 13 and 14 in central Graham Island and at Section 4 on Maude Island.

The Phantom Creek Formation is underlain by the greenish grey siltstones of the Whiteaves Formation. The contact is exposed at seven known localities in the Queen Charlotte Islands and, except for the sequence at Section 12, is abrupt with no transitional beds. At Section 12 the siltstones of the Whiteaves Formation coarsen over about 20 cm before the well bedded, hard sandstones of the Phantom Creek Formation begin.

DISCUSSION

The type section of the Phantom Creek Formation was designated by Cameron and Tipper (1985) to be Section 12 and this still remains the most suitable despite some changes in its interpretation. Due to the complicated structure in this area and the generally high river levels, this section has been misinterpreted in the past, both by the author and by Cameron and Tipper. The section, as described by Cameron and Tipper, extends upsection from the Whiteaves Formation/Phantom Creek Formation contact in a downstream direction. During the 1988 field season, I noted that the Whiteaves Formation/Phantom Creek Formation contact was actually a fault contact, and because of the presence of a well bedded coquina at the downstream end of the section, suspected that the section's base was actually downstream

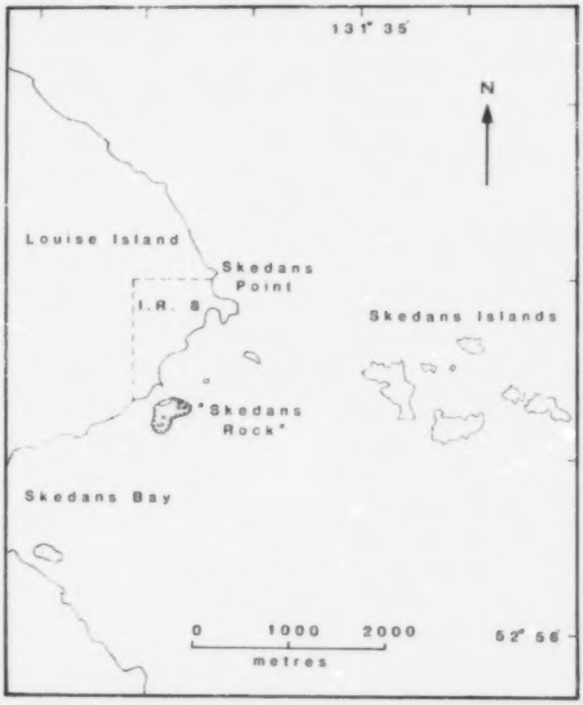

Figure 2. Location of 'Skedans Rock' on the east coast of Louise Island.

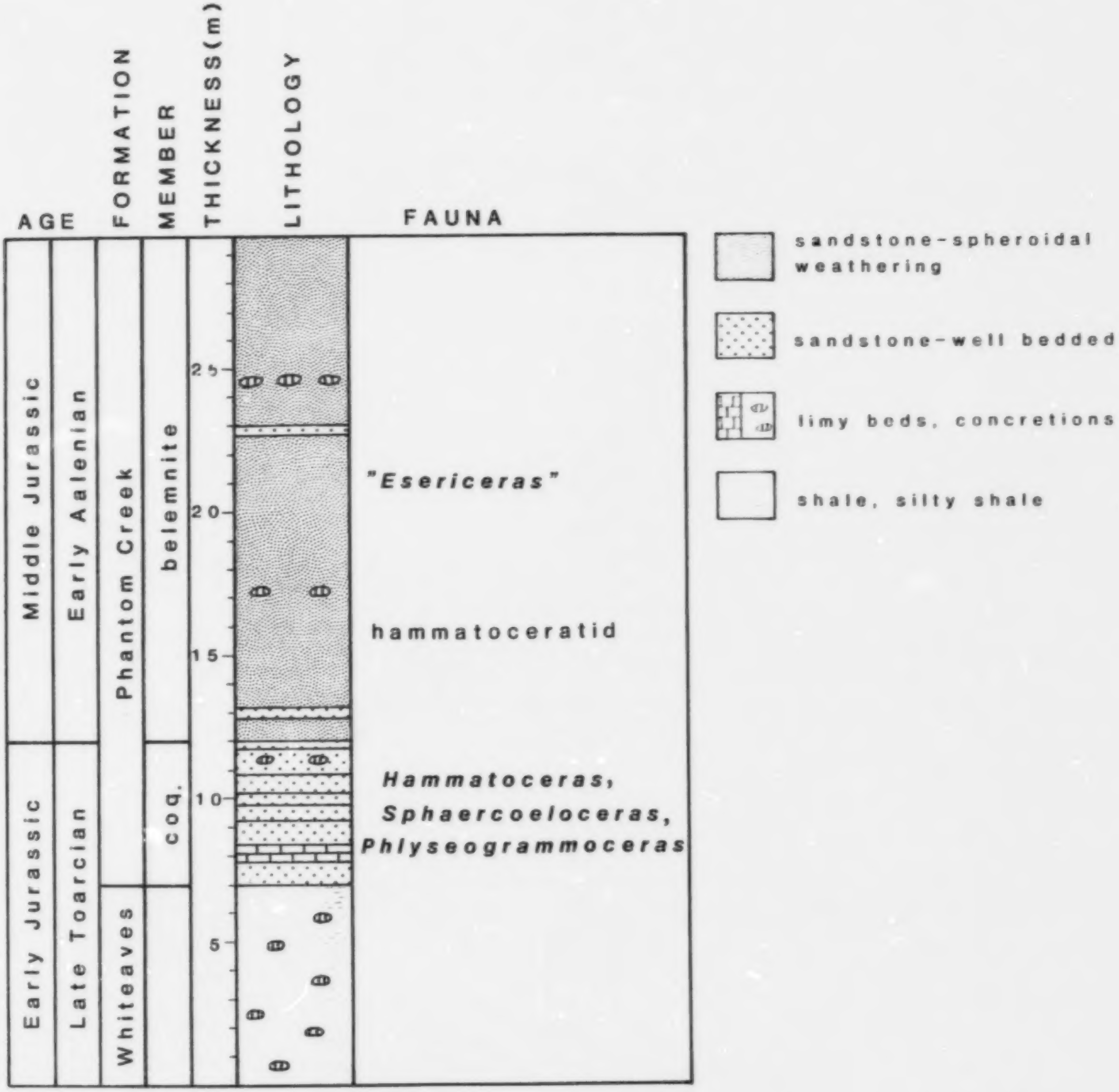
AGE
FORMATION
MEMBER
THICKNESS(m)
LITHOLOGY
FAUNA
Middle Jurassic
Early Aalenian
Phantom Creek
belemnite
Early Jurassic
Late Toarcian
Whiteaves
coq.
25
20
15
10
5
"Esericeras"
hammatoceratid
Hammatoceras,
Sphaercoeloceras,
Phlyseogrammoceras
sandstone-spheroidal weathering
sandstone-well bedded
limy beds, concretions
shale, silty shale

Figure 3. Revised stratigraphic column of the type section of the Phantom Creek Formation (Section 12) and the positions of some important fauna.

and that upsection was upstream. Two observations made during the past summer, aided by extremely low water levels, confirm that this is indeed the case. An outcrop of the recessive Whiteaves Formation was exposed at the base (downstream portion) of the section and conformably underlies the Phantom Creek Formation (Fig. 2). Low water levels also exposed much more of the Phantom Creek Formation along with a number of left lateral faults that, if unaccounted for, increase the apparent thickness of the section by approximately 5 to 10 m. It also appears now that the majority of the Phantom Creek Formation, principally the belemnite sandstone member, is Aalenian in age and that the coquinoid sandstone member is restricted to the upper Upper Toarcian. At Section 12 the basal, well bedded coquinoid layers are highly fossiliferous and contain several latest Toarcian genera such as *Sphaercoeloceras*, *Hammatoceras*, and *Phlyseogrammoceras* which are in the Levesquei zone of northwestern Europe. Above these beds is the belemnite sandstone member with rare and commonly poorly preserved ammonites. The most common is the large, involute ammonite referred to as *'Esericeras'* by Frebold (H. Frebold, unpublished data; Cameron and Tipper, 1985; Jakobs, 1989), thought to be Late Toarcian in age. Further study, however, has revealed that its reported occurrence with *Hammatoceras* and *Sphaercoeloceras* (Jakobs, 1989) was in error. It now appears that it may be Early Aalenian in age based on its stratigraphic position above an Aalenian-like hammatoceratid, its similarity to certain Aalenian forms and the absence of dicoelitid belemnites (generally regarded as Toarcian indicators in this area).

Section 4 on Maude Island has proved to be problematical in the past, and a second visit was made there this past summer. Several conclusions were reached concerning the Whiteaves Formation/Phantom Creek formation contact there and the supposed 'paleosoil' found at the contact (Cameron and Tipper, 1985; Jakobs, 1989). The sandstones above the Whiteaves Formation are dark grey and medium to coarse grained with no ammonites and only a few belemnites. Although the sandstones are not typical of the Phantom Creek Formation, the contact with the underlying Whiteaves Formation does not appear to be faulted and the sandstones probably represent the belemnite sandstone member; the coquinoid sandstone member may be absent due to erosion. The 'paleosoil' of Cameron and Tipper is a 10 cm thick layer of a soft clay-like material which is actually the remains of a concretionary bed. Excavation into the soft 'paleosoil' material, to a depth of 30 cm, produced several waterworn concretionary blocks. A second 'paleosoil' bed was encountered approximately 30 cm below the first. Farther down in the Whiteaves Formation several oval bodies of 'paleosoil' material were encountered beneath a thin covering of overburden. Excavation of the material revealed that they were about 40 cm across and ellipsoidal in shape. In addition, several showed a black veining pattern of clayey material with calcite-fragments which bear a resemblance to the calcite filled cracks of septarian concretions.

A visit was made this past summer to Skedans Rock, a small island south of Skedans Indian Reserve on the east coast of Louise Island (Fig. 3). Reports of Toarcian ammonites and strata found by P. Lewis (personal communication, 1988), indicated that this could be the southernmost occurrence of the Toarcian in the Queen Charlotte Islands (Jakobs, 1989). Most of the intertidal area is underlain by Whiteaves Formation and a number of good ammonites were collected, but because of complex structure and the lack of good marker beds, a section was not measured. The contact with the overlying Phantom Creek Formation was well exposed and apparently not faulted. The Phantom Creek Formation fauna contained no ammonites, a few bivalves, and mostly belemnites. It appears that the coquinoid sandstone member is here also absent due to erosion, and that the exposed Phantom Creek Formation is Aalenian in age.

The variation, across the Queen Charlotte Islands, in the duration of the hiatus could be related to the paleotopography of the area at the time of deposition. A paleo-high in the south would be more greatly affected by a regression than a paleo-low area to the north in Central Graham Island.

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Stratigraphy and sedimentology of the Longarm Formation, southern Queen Charlotte Islands, British Columbia[1]

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Abstract

The Longarm Formation unconformably overlies a variety of lithological units in the southern Queen Charlotte Islands, including lower and upper Kunga Group strata of Late Triassic age, Lower Jurassic Sandilands Formation, and Upper Jurassic plutonic rocks. The oldest fauna found in the Longarm Formation in the southern islands is Hauterivian; younger, Barremian age strata also occur. The presence of Aptian strata, although not yet proved with faunal data, is considered likely. The Longarm Formation sections in this region exhibit an overall fining-upward trend reflecting a transgressive event. The lithological succession, sedimentary structures, and associated macrofauna indicate that the formation accumulated in shelf environments.

Résumé

La formation de Longarm repose en discordance sur diverses unités lithologiques dans la partie sud des îles de la Reine-Charlotte, comprenant les couches inférieure et supérieure du groupe de Kunga du Trias supérieur, la formation de Sandilands du Jurassique inférieur et les roches plutoniques du Jurassique supérieur. La faune la plus ancienne découverte dans la formation de Longarm dans les îles sud sont d'âge hauterivien; on trouve en outre des couches plus jeunes du Barrémien. La présence de couches aptiennes, bien qu'elles n'aient pas encore été datées par une faune, est considérée vraisemblable. Les coups de la formation de Longarm dans cette région montrent une tendance générale d'un granoclassement normal reflétant une transgression. La succession lithologique, les structures sédimentaires et la macrofaune associée indiquent que la formation s'est construite dans des milieux peu profonds.

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INTRODUCTION

The Longarm Formation was informally proposed by Sutherland Brown (1968) for a sequence of conglomerate, sandstone, siltstone, and shale which is found at many localities in the Queen Charlotte Islands. The formation, as it was defined, is distinctly older than the mid-Cretaceous (Albian to Santonian) Queen Charlotte Group. Sutherland Brown (1968) suggested that the Longarm Formation reflected a variety of depositional environments ranging from nearshore marine to turbidite basin facies, all deposited in a "narrow graben-like trough" (Sutherland Brown, 1968, p. 151).

This interpretation of the Longarm sedimentology was subsequently embraced by Yorath and Chase (1981) who suggested that the Longarm Formation represented a "suture assemblage" that accumulated in a narrow basin as a result of collision of the Wrangell and Alexander terranes.

A study of the stratigraphy and depositional environments of the Longarm Formation was begun by Haggart in 1988. Results from studies of the formation in the northern half of the Queen Charlotte Islands indicate that the formation reflects a single transgressive episode in that area, is much more widespread than previously realized, and represents a variety of predominantly shelf depositional environments (Haggart, 1989a). On this basis Haggart (1989b) subsequently suggested that the concept of a "suture assemblage" as applied to the Longarm Formation is likely incorrect.

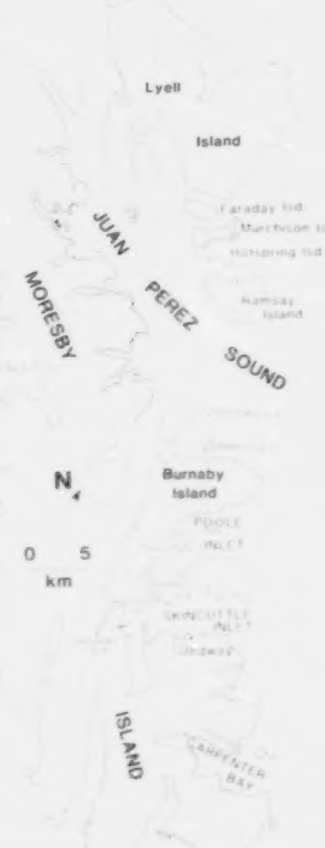

Figure 1. Map of southern Queen Charlotte Islands showing main localities discussed in text.

The objective of the 1989 field season was to examine Longarm Formation exposures in the southern part of the archipelago and to compare and contrast them with the more northerly outcrops.

STRATIGRAPHY

All localities of the Longarm Formation identified by Sutherland Brown (1968, Fig. 5) in the southern Queen Charlotte Islands were visited, except for Hotspring Island and the isolated outcrop near Jedway. Stratigraphic sections were measured where possible and megafossil and microfossil collections were made.

Good stratigraphic sections are located at Carpenter Bay, in Poole Inlet, on Huston Point in Skincuttle Inlet, on Arichika Island, and on Ramsay and Murchison islands (Fig. 1). Exposures mapped as Longarm Formation by Sutherland Brown on Boulder Island in western Skincuttle Inlet are probably correlative with the Yakoun Group or Maude Group: a microfossil sample from the shale section on this island yielded probable Jurassic radiolarians. Likewise, the thick section of conglomerate, sandstone, and shale on Lyell Island previously mapped as Longarm Formation produced Bajocian ammonites (H.W. Tipper, personal communication, 1989) from one locality and is thus considered a probable Yakoun Group equivalent.

Exposures on Faraday and Alder islands are too poor to confirm the presence of Longarm strata, but we think it unlikely that Longarm rocks occur at either of these localities.

Basal unconformity

The Longarm Formation unconformably overlies a variety of stratigraphic units in the southern islands. At Carpenter Bay, a basal contact was not seen. However, the lower part of the formation is in fault contact with probable Lower Jurassic Sandilands Formation strata and is thus thought to onlap that unit. On Arichika, Murchison, and Ramsay islands in the northern part of the study area, and at Huston Point in Skincuttle Inlet, the formation overlies the Upper Triassic Peril Formation (of Desrochers and Orchard, 1990) of the Kunga Group, whereas on Bolkus Island the basal beds onlap the Sadler Limestone of the lower part of the Kunga Group. At Rebecca Point in Poole Inlet, the formation onlaps Late Jurassic granitoid rocks of the Burnaby Island plutonic suite (Anderson and Greig, 1989).

Age

Although molluscs are generally uncommon in the Longarm Formation outcrops in the southern Queen Charlotte Islands, they do occur in sufficient numbers that an approximate age limit for the formation may be established. The most common faunal elements are belemnites of the genus *Acroteuthis*, inoceramid bivalves, and trigoniid bivalves. Ammonites are relatively rare.

Jeletzky (*in* Sutherland Brown, 1968) identified belemnoids from Iron Point in Carpenter Bay as belonging to the genus *Pachyteuthis* and thus suggested correlation of those outcrops with the Yakoun Group. No further examples of this genus were found in 1989, but examples of *Acroteuthis*, some of great size, are common in this area. As Yakoun Group rocks are known from the south shore of Carpenter Bay (Sutherland Brown, 1968), it is possible that unrecognized exposures of that unit in the Iron Point area may have furnished the collection studied by Jeletzky.

No examples of the Late Valanginian bivalve *Buchia crassicollis* (Keyserling), which is found in the western Skidegate Inlet region of the Queen Charlotte Islands, were collected from the southern islands. The oldest fauna collected appears to be that characterized by the bivalves *Inoceramus colonicus* Anderson and *I.* cf. *paraketzovi* Efimova, indicative of a Hauterivian age (Jeletzky, 1970) and collected at Poole Inlet and Ramsay Island. Younger beds are represented by occurrences of the trigoniid bivalve *Quoiecchia* ex gr. *aliciae* Crickmay as well as the ammonite genus *Shasticrioceras*.

No definite faunal evidence for Aptian strata, such as occurs at Cumshewa Inlet (Haggart, 1989a), was found in the formation in the southern Queen Charlotte Islands. However, the thick and sparsely fossiliferous mudstone succession which overlies the more mollusc-rich sandstones of the formation may indeed include younger, Aptian-age, strata.

SEDIMENTOLOGY

Six distinct lithofacies comprise the Longarm Formation in the southern Queen Charlotte Islands. The succession of these facies in the Longarm section represents a transgressive marine sequence. In general, the six lithofacies succeed each other up section but not all six lithofacies are present in every section and the stratal thicknesses comprising each lithofacies are highly variable. From base to top they include: (1) basal transgressive lag lithofacies; (2) interbedded conglomerate and sandstone lithofacies; (3) bioturbated sandstone lithofacies; (4) sandstone/siltstone storm deposits lithofacies; (5) laminated siltstone and mudstone lithofacies; and (6) turbidite lithofacies.

Figure 2. Cobble conglomerate of the basal transgressive lag lithofacies, Arichika Island.

Basal transgressive lag lithofacies

The base of the Longarm Formation is generally characterized by a thin transgressive lag composed of poorly sorted, angular to well rounded framework cobble conglomerate (Fig. 2). This facies, when present, ranges up to several metres in thickness. Fossils are rare within the conglomerate lag but oysters and trigoniid bivalves indicate a shallow marine environment.

The morphology of clasts in the lag conglomerate appears to be a function of clast composition. Clasts of Sandilands Formation or Peril Formation are generally angular whereas Sadler Limestone clasts and granitoid clasts are more rounded. The clasts range from pebbles to large boulders several metres or more across.

Sub-Longarm topographic features and sediment availability appear to have strongly influenced lag accumulations. At Rebecca Point in Poole Inlet well rounded granitic boulders up to 3 m in diameter, weathered from the underlying exposed pluton, form a lag up to 3 m in thickness. The lag represents reworked beach deposits presumably derived from an adjacent headland. The absence of lag at some locales suggests that the Longarm coastline consisted of headlands and embayments.

Interbedded conglomerate and sandstone lithofacies

This lithofacies is composed of interbedded trough to low-angle cross-stratified sandstone and conglomerate (Fig. 3). On Arichika Island the conglomerate occurs as sharply based tabular units up to 1.5 m in thickness. These units pinch and swell laterally. Internally, the conglomerates are framework, poorly sorted, subrounded to well rounded, and exhibit small-scale, low-angle trough cross-stratification. The clasts consists of subequal amounts of Yakoun volcanics and Kunga argillite lithologies, and minor granitoid rocks. The distinctive black and white "granular conglomerate" of Sutherland Brown (1968) is characteristic of this lithofacies. Scattered *Inoceramus* fragments are found within the conglomerates.

Figure 3. Interbedded conglomerate and sandstone lithofacies, Arichika Island.

Conglomeratic units are abruptly overlain by tabular units of trough cross-stratified, fine to medium grained pebbly greywacke (Fig. 4). Sets up to 40 cm thick form sequences up to 3 m thick composed of grouped cosets. Some cross-stratified sandstone units contain abundant *Inoceramus* valves. The sandstones exhibit only minor bioturbation, concentrated near the tops of sets.

The conglomerate and sandstone lithofacies is interpreted as being deposited within a shallow foreshore environment. Storm-induced wave activity reworked gravelly beach deposits, resedimenting them as gravelly bedforms upon the shallow shoreface. The cross-stratified sandstones represent the deposits of longshore migrating sinuous crested megaripples (Fig. 5).

Bioturbated sandstone lithofacies

This lithofacies is composed primarily of horizontally laminated to low-angle cross-stratified, silty, fine grained bioturbated greywacke, with minor interbedded mudstone and siltstone. Sharp-based units up to 75 cm in thickness composed of low-angle laminated sandstone are gradationally overlain by bioturbated silty sandstone (Fig. 6). These units represent individual storm events, with the low-angle laminated sandstone interpreted as swaley cross-stratification. Tree fragments up to 3 m in length, abundant smaller plant debris, and scattered ammonites, belemnites, and trigoniid bivalves occur throughout this lithofacies; *Inoceramus* fragments are rare.

This lithofacies is interpreted as deposited within a deeper shoreface setting, beneath fairweather wave base but above storm wave base. The relative thickness of the facies in many sections suggests that this depth range characterized the majority of the Longarm shelf.

Sandstone/siltstone storm deposits lithofacies

Composed primarily of storm deposits forming units up to 30 cm in thickness, this lithofacies, in general, abruptly overlies the bioturbated sandstone lithofacies. The storm deposit units are characterized by abrupt, planar bases overlain by horizontal to low-angle planar tabular laminated, very fine sandstone or siltstone. This is gradationally overlain by a heavily bioturbated silty mudstone, which forms the cap of the storm deposit (Fig. 7). These sequences exhibit abundant load structures and other evidence of soft-sediment deformation, indicative of rapid sediment accumulation (Reineck and Singh, 1980). On Ramsay Island, rare interbedded, small-scale trough cross-stratified granular sandstone units up to 40 cm thick occur within the finer grained storm deposits.

Laminated siltstone and mudstone lithofacies

Laminated siltstones and mudstones with thin interbedded storm deposits and minor, small calcareous concretions characterize this lithofacies (Fig. 8). The storm deposits reach 2 cm in thickness and often include a basal intraclastic pebble conglomerate overlain by laminated siltstone and mudstone. The intraclasts are generally flat and are presumably derived from the laminated caps of the underlying storm sequence. Bioturbation within the facies is common and diverse. Near the top of the lithofacies on Murchison Island, units of horizontally laminated, fine grained sandstone and massive pebble conglomerate occur interbedded with laminated mudstones and siltstones.

Figure 4. Interbedded conglomerate and sandstone lithofacies, Arichika Island; outcrop about 8 m in height.

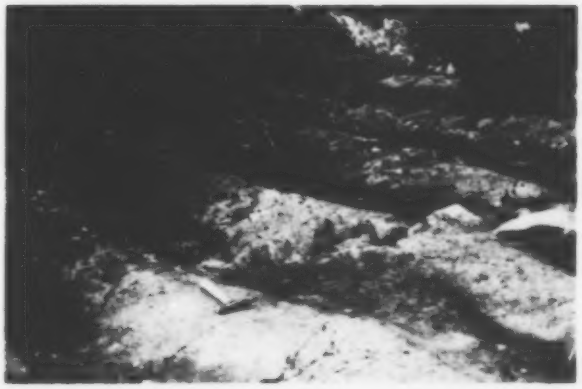

Figure 5. Megaripples developed on upper surface of granular sandstone bed, interbedded conglomerate and sandstone lithofacies, Carpenter Bay.

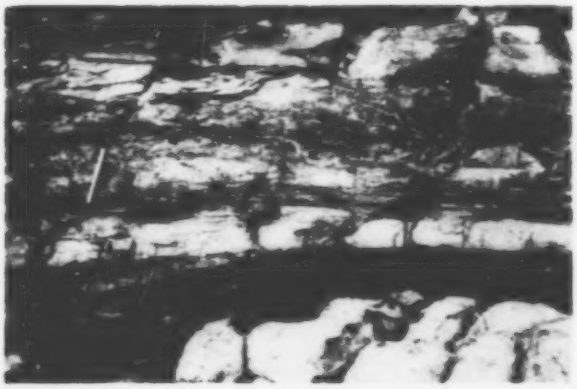

Figure 6. Silty bioturbated beds of bioturbated sandstone lithofacies.

The lithofacies is interpreted as an offshore muddy shelf deposit. Deposition was punctuated by storm events, which led to the formation of the thin intraclastic units. The thick sandstone and conglomeratic units near the top of the sequence may be the deposits of turbidity currents.

Turbidite lithofacies

The turbidite lithofacies was seen only on Ramsay Island where it attains a thickness of at least 20 m. This facies is composed of thinly bedded turbidites with interbedded channelized sandy turbidites (Fig. 9). The thinly bedded turbidites exhibit well developed Bouma Tabce and Tbce divisions. The channelized turbidites are composed of fine to medium grained greywacke and reach 120 cm in thickness. These units exhibit the Tabc divisions of Bouma and contain scattered intraclasts near their base, which is scoured. No molluscs were noted in these strata.

This lithofacies is interpreted as submarine channel levee deposits.

DISCUSSION

The composition of the basal conglomeratic lag at any given locality is strongly reflective of the rock type comprising the sub-Longarm surface. Where present, the lag conglomerate invariably includes a high proportion of clasts, in most cases close to 100 %, which are derived from the immediate sub-Longarm unit. The proportion of these clasts drops within metres upsection, however, as they are replaced by clasts of Yakoun Group volcanics. If not present in the basal lag, Yakoun Group clasts always appear at some point within

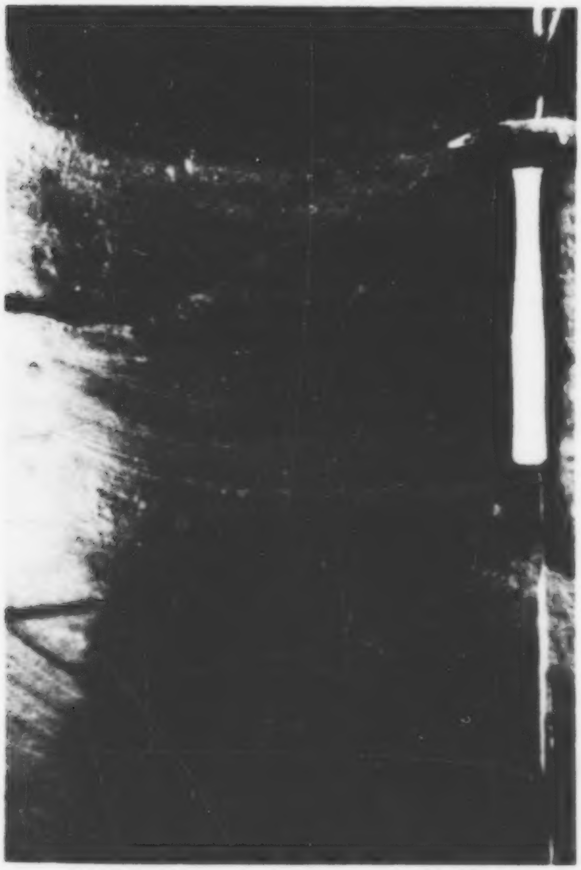

Figure 7. Storm-deposit sequence of planar laminated sandstone capped by bioturbated silty mudstone, sandstone/siltstone storm deposits lithofacies, Ramsay Island.

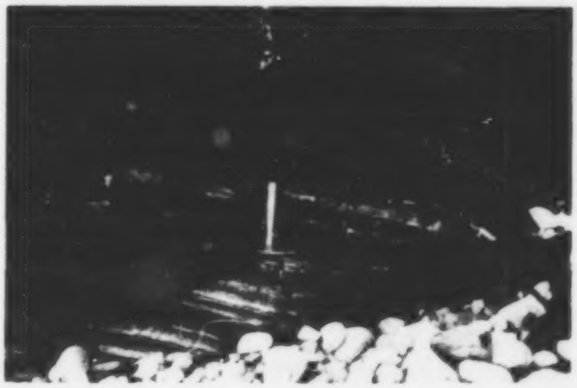

Figure 8. Laminated siltstone and mudstone lithofacies, Murchison Island.

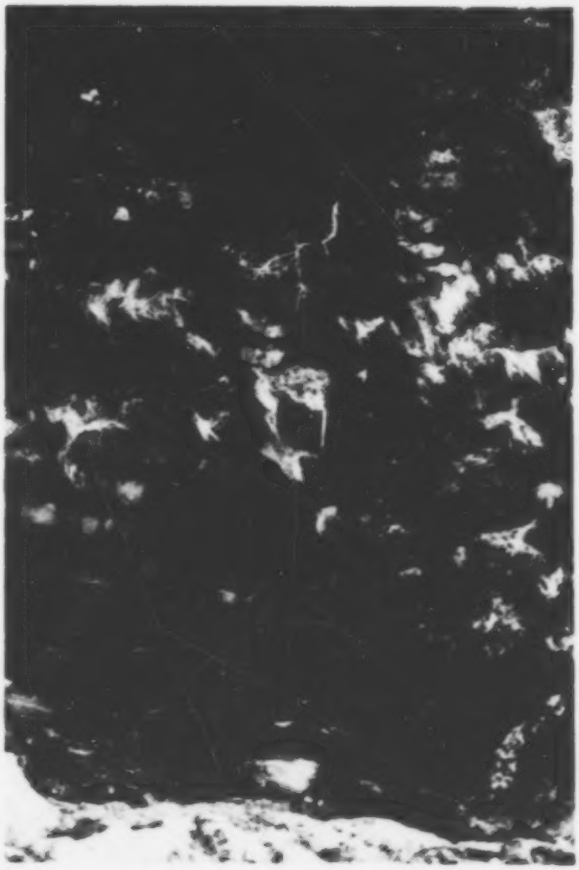

Figure 9. Thinly bedded turbidites of uppermost lithofacies observed in Longarm Formation, turbidite lithofacies, Ramsay Island.

each stratigraphic section, indicating widespread distribution of this source unit during deposition of the formation.

The vertical succession of lithofacies present in the Longarm Formation represents a transgressive sequence, from shallow shoreface through offshore deposits, to deeper basinal deposits in the uppermost part. The facies present in the lower and middle part of the formation indicate that the Cretaceous shelf was storm dominated. The great thickness of shelf deposits present at Arichika Island indicates that deposition occurred within a regime of rapid relative sea level rise coupled with a slightly less-rapid rate of sediment influx.

The Longarm Formation in the southern Queen Charlotte Islands is thus a similar sequence to that observed in the northern part of the islands (Haggart, 1989a). In both regions the formation consists of a transgressive marine succession, deposited in predominantly shallow-marine environments and widespread in its distribution. In both regions the formation spans a similar time period and only one transgressive cycle is represented within the formation. Deposition of the formation was controlled in great measure by relative sea level rise. In these respects the Longarm Formation is similar to the younger Haida Formation of the Queen Charlotte Group.

The interpretation of Yorath and Chase (1981) that the Longarm Formation represents a "suture assemblage" resultant from terrane collision does not appear appropriate. Such assemblages are regressive in nature and characterized by a flysch to molasse sequence produced from rapid basin infilling. The predominantly shallow-marine nature of the Longarm Formation, its widespread distribution, and its transgressive aspect, all argue strongly against deposition as a result of terrane collision.

The occurrence of other Cretaceous transgressive marine successions on the west coast, such as the Cape Sebastian Sandstone of Oregon (Bourgeois, 1980) and the Chico and Redding formations of northern California (Haggart, 1986), indicate that the regime of rapid sea level rise and abundant sediment supply which characterizes deposition of the Longarm Formation was common along the western margin of North America during the later Mesozoic.

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Sedimentology of the Upper Cretaceous Queen Charlotte Group, with special reference to the Honna Formation, Queen Charlotte Islands, British Columbia[1]

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Abstract

The Upper Cretaceous Queen Charlotte Group represents a transgressive sequence deposited in a marine basin created in Late Jurassic to Early Cretaceous time. The group includes the sandy, inner shelf to muddy, outer shelf and slope deposits of the Haida Formation, which are westwardly transitional into a submarine fan complex represented by the Skidegate and Honna formations. Several submarine fan complexes can be recognized, each characterized by a radial arrangement of channels in the inner fan area. Initiation of fan sedimentation was triggered by a eustatic sea level drop or by uplift to the east.

Résumé

Le groupe de Queen Charlotte du Crétacé supérieur représente une série transgressive déposée dans un bassin marin formé entre le Jurassique supérieur et le Crétacé inférieur. Le groupe comprend des dépôts sableux de plate-forme continentale interne à des dépôts boueux de plate-forme continentale externe ainsi que des dépôts de pente de la formation de Haida, qui passent progressivement vers l'ouest à un complexe de cônes d'éboulis sous-marins représenté par les formations de Skidegate et de Honna. On peut reconnaître plusieurs complexes de cônes sous-marins, chacun étant caractérisé par une disposition radiale de chenaux dans son secteur interne. Le démarrage de la sédimentation des cônes a été déclenché par une baisse ou par une montée du niveau marin eustatique vers l'est.

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INTRODUCTION

The mid-Cretaceous Queen Charlotte Group is a transgressive marine succession comprising the Haida Formation (Albian to Cenomanian), the Skidegate Formation (Cenomanian to Turonian), the Honna Formation (Coniacian), and an unnamed sequence of Santonian mudstones which overlies the Honna Formation with unknown stratigraphic relationship (Haggart, 1986; Haggart et al., 1989). The Queen Charlotte Group is underlain with uncertain stratigraphic relationship by the Upper Jurassic to Lower Cretaceous (Hauterivian to Aptian) Longarm Formation (Haggart, 1989; Haggart et al., 1989). The Longarm Formation has been interpreted as a transgressive marine sequence, ranging from shallow, storm-dominated shelf to submarine fan depositional environments (Haggart, 1989; Haggart and Gamba, 1990). The formation was probably deposited in the same basin as the younger Queen Charlotte Group, and hence represents an earlier transgressive episode (Haggart and Gamba, 1990).

During the 1989 field season regional paleocurrent analysis of the Honna and Skidegate formations was undertaken. These data, coupled with sedimentological observations from other parts of the Queen Charlotte Group, lend new insights into the morphology of the mid-Cretaceous basin and the depositional systems which operated within it.

DEPOSITIONAL ENVIRONMENTS OF THE QUEEN CHARLOTTE GROUP

Haida Formation

The Haida Formation was subdivided into a lower sandstone member and an upper shale member by Sutherland Brown (1968). The base of the sandstone member was interpreted as fluviatile in nature by Fogarassy (1989). However, we saw no fluvial deposits at the base of the sandstone member in Cumshewa and Skidegate inlets or at Langara Island and Pillar Bay, and the unit is in fact a storm-dominated shallow shelf deposit, as suggested by Haggart (1986) and Higgs (1988).

The gradationally overlying shale member was interpreted as a muddy, outer shelf sequence by Haggart (1986). The shale member can be divided into a lower, muddy, outer-shelf submember and an upper, muddy-slope submember. The shelf environment is characterized by bioturbated, lenticular-bedded siltstones and mudstones. In contrast, the slope environment is characterized by laminated mudstones and features slump horizons up to 3 m in thickness, composed of chaotically bedded laminated mudstone, observed on a small island to the west of Lina Island in Skidegate Inlet. One such horizon, to the west of Skidegate Narrows on Graham Island, indicates a downslope direction to the southwest.

Skidegate Formation

The thinly bedded turbidites of the Skidegate Formation interfinger with the Haida shale member, making formational divisions between the two units cumbersome. The turbidites exhibit well developed Bouma sequences, ranging from complete Tabcde sequences up to 20 cm in thickness to relatively incomplete Tbce and Tce sequences 5-8 cm thick. Soft-sediment deformation, dewatering structures, and slump structures pervade the sequence. These features are suggestive of rapid deposition and, coupled with the well developed nature of the Bouma sequences and the proximity to the overlying channelized turbidites of the Honna Formation, suggest that the thinly bedded turbidites of the Skidegate Formation are levee deposits. Modern submarine fans, such as the Amazon fan, exhibit similar levee deposits associated with channels up to 500 m thick and 25 km wide (Damuth et al., 1983). Paleocurrent measurements collected from ripple laminations within the Skidegate Formation at Sewell Inlet indicate a southwards transport direction, perpendicular to the west-directed flow in channelized turbidites of the overlying Honna Formation. This perpendicular relationship between channels and flanking levees is characteristic of most submarine fan complexes (Walker, 1989). On the basis of ammonite biostratigraphy, Haggart (1986) inferred a time equivalence between the Haida shale member and the Skidegate Formation which, taken with regional map patterns, indicates an east to west deepening of the basin.

Honna Formation

The overlying Honna Formation exhibits one of three stratigraphic relationships with the stratigraphically underlying unit: abruptly overlies the Haida shale (Langara Island); abruptly overlies the Skidegate Formation (Skidegate Inlet); or interfingers with the Skidegate Formation (Sewell Inlet and central Graham Island). The basal contact of the Honna Formation shows only minor scour and is concordant with the stratigraphically underlying unit. The Honna Formation was interpreted as an alluvial fan to submarine fan complex by Sutherland Brown et al. (1983), as a submarine fan by Yagishita (1985), and as a slope-apron fan by Higgs (1988). Provenance (Yagishita, 1985) and paleocurrent (Higgs, 1988) data indicate an eastern source (possibly the Coast Mountains) and a westward direction of transport. The Honna Formation is composed primarily of channelized conglomeratic turbidites, with minor channelized sandstones and interbedded sequences of sandstone and siltstone. Fogarassy and Barnes (1988) subdivided the Honna Formation into a basal and upper conglomeratic member and a middle sandstone member. These subdivisions are not obvious on a regional scale and are applicable only to the Skidegate Inlet area. On the west side of Lina Island in western Skidegate Inlet, a thick (25 m) sequence of interbedded sandstone occurs within primarily conglomeratic sequences of the Honna Formation. This sequence is composed primarily of low angle, possibly hummocky, cross-stratified sandstone with interbedded, horizontally laminated sandstone exhibiting parting current lamination and current rippled sandstones. Paleocurrent indicators from the latter two structures indicate a west-northwest direction of transport. A similar 10 m-thick sequence of thinly bedded silty turbidites occurs in the Honna Formation at Conglomerate Point in Cumshewa Inlet. The thinly bedded turbidites exhibit the Tae divisions of Bouma and are suggestive of lobe abandonment and deposition by weak turbidity currents. In the Langara Island area, a thick sequence of laminated mudstone is interbedded within channelized conglomerates near the top of the Honna Formation, also indicating lobe abandonment.

In the Long Inlet area, the Honna Formation is capped by a succession of interbedded shallow marine to subaerial volcanics and siliciclastics (Haggart et al., 1989). The sediments consist of matrix-supported breccias, interpreted as debris flows, and horizontally bedded conglomerates and sandstones, interpreted as hyperconcentrated flood flows. These flows are triggered by explosive volcanic events and catastrophic discharge of water, and are a common feature in volcanically active areas such as the Cascade Mountains in Washington State (Smith, 1986).

Santonian unit

A sequence of Santonian mudstones overlies the Honna Formation with uncertain stratigraphic relationship in the Skidegate Inlet area. Haggart and Higgs (1989) interpreted the mudstones as deposited within an outer shelf environment. On northwest Graham Island at Pillar Bay, the Honna Formation is abruptly and conformably overlain by a similar mudstone sequence, which may be correlative with the Santonian mudstones of the Skidegate Inlet area.

PALEOCURRENT ANALYSIS OF THE HONNA FORMATION

Thirty-six stations within the Honna Formation were chosen for paleocurrent analysis. As the goal of the study was to obtain a regional paleogeographic reconstruction of the Honna fan system, stations were chosen to represent all the major Honna outcrop areas in the islands (Fig. 1). Measurement of the a-b plane orientations of 25 flattened discoid clasts was made at each station, with each station being restricted to a single depositional unit of channelized conglomerate. In addition, most stations were chosen to be as close to the base of the formation as possible (within the basal 50 m), so that a rough time equivalency could be established between stations from widely separated areas. The data were corrected for tectonic tilt and the results plotted using the standard computer programs. All stations showed statistically significant trends.

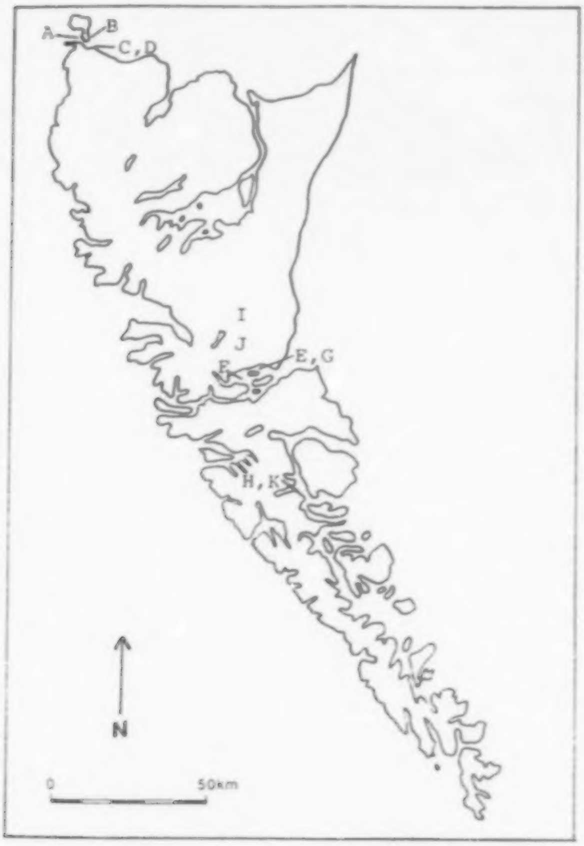

Figure 1. Locations of paleocurrent stations. A-western Langara Island, B-eastern Langara Island, C-northern Graham Island (base), D-northern Graham Island (top), E-Lina Narrows, F-Legace Island, G-western Lina Narrows, H-Sewell Inlet, I-Ghost Creek, J-Honna River, K-Sewell Inlet.

Table 1. Paleocurrent data

Station	Vector mean	Resultant
A1	14.9	0.57
2	16.3	0.46
3	28.4	0.50
4	243.2	0.94
5	243.1	0.93
B1	289.1	0.59
2	280.6	0.84
3	231.9	0.57
C1	274.8	0.94
2	298.9	0.94
3	21.6	0.92
4	305.9	0.91
D1	47.8	0.79
2	353.1	0.79
E1	19.7	0.48
2	10.8	0.61
3	14.6	0.90
4	30.6	0.67
5	47.8	0.79
F1	258.9	0.53
2	221.6	0.65
3	261.0	0.50
4	230.9	0.30
5	238.4	0.92
G1	344.7	0.83
2	325.3	0.92
3	318.8	0.89
H1	323.0	0.89
2	304.0	0.87
3	294.0	0.92
4	316.0	0.82
I1	277.0	0.78
J1	46.0	0.54
2	72.0	0.70
3	86.0	0.65
K1	232.0	0.76

Northern Graham Island

The rotated data reveal two primary trends, one westward, the other north-northeastward (Table 1 and Fig. 2). At stations A-1 to A-5 on western Langara Island, paleocurrent trends swing from north-northeast at the base of the section to west-southwest upsection over a distance of some 20 m. A similar rapid vertical swing in paleocurrent direction was observed at station C-1 to C-4 on northern Graham Island, from west-northwest to north-northeast and back to northwest over a vertical distance of 15-20 m. A west-northwest to west-southwest trend was determined from the top of the Honna Formation at stations B-1 to B-3 on eastern Langara Island. A northeasterly and a north-northwesterly trend were obtained from the top of the Honna Formation at stations D-1 and D-2 at Pillar Bay on northern Graham Island (Fig. 3).

Central Graham Island

Within central Graham Island, a northeasterly to east-northeasterly trend was observed at stations J-1 to J-3, located near the base of the Honna Formation on Honna River. A single station at Ghost Creek, station I-1, revealed a west-northwestward trend.

Skidegate Inlet

Stations E-1 to E-5, located at the base of the Honna Formation at eastern Lina Narrows, reveal a consistent north-northeasterly trend, while just 5 km to the west at Legace Island, correlative stations F-1 to F-5 exhibit a consistent southwestward trend (Fig 4). However, paleocurrents obtained from the top of the Honna Formation section on the west side of Lina Narrows (stations G-1 to G-3), some several hundred metres upsection, reveal a consistent northwestward trend, suggesting a counterclockwise swing in flow direction over time (Fig. 4).

Sewell Inlet

Stations H-1 to H-4, located at the base of the Honna Formation where it interfingers with the Skidegate Formation, reveal a strong consistent northwestward trend. Paleocurrents collected from the underlying Skidegate Formation at station K-1 reveal a consistent southwestward trend, at right angles to that of the overlying Honna Formation.

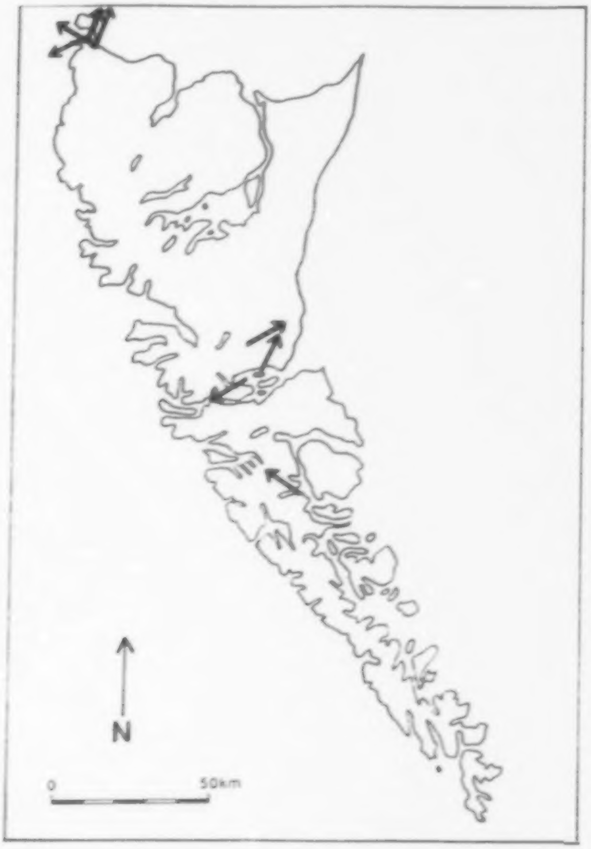

Figure 2. Paleocurrent trends from the base of the Honna Formation, with tail of arrow situated at locality.

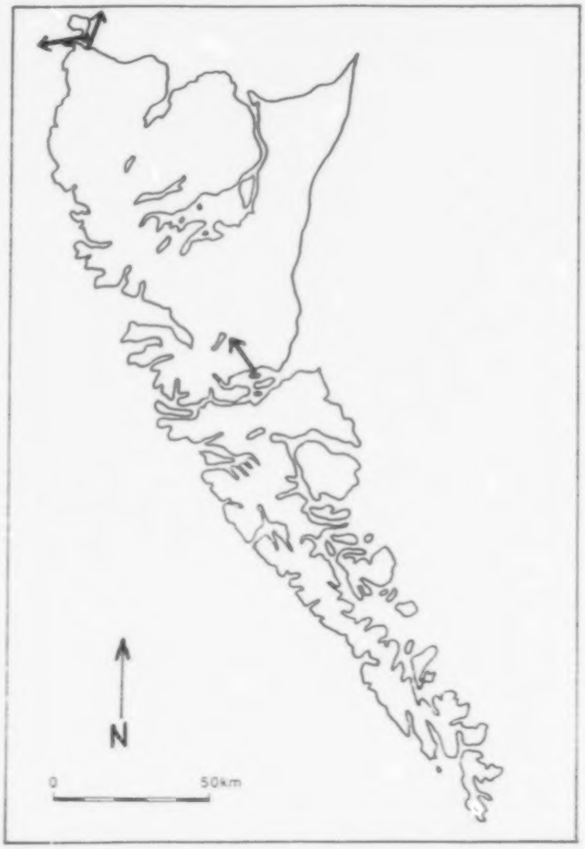

Figure 3. Paleocurrent trends from the top of the Honna Formation, with tail of arrow situated at locality.

Interpretation

The paleocurrent data obtained from channelized turbidites of the Honna Formation reveal marked variations in flow direction, both laterally as in the Skidegate Inlet area, and upsection as in the Langara Island area. Higgs (1988) recognized the divergence within the Skidegate Inlet area based on his own paleocurrent measurements. He interpreted the northerly trend at eastern Lina Narrows as an artifact of block rotation postdating deposition of the Honna Formation, suggesting that the trend was originally westward, consistent with that observed at other localities.

The observation of northwestward-directed flow at higher stratigraphic levels in the Honna Formation at western Lina Narrows and the negative evidence for large scale block rotations (R.I. Thompson, personal communication 1989) seriously weakens the block rotation hypothesis. A preferred hypothesis is that both the vertical variation at individual localities and the differences between correlative stations at different localities reflect the shifting of the radial disposition of channels upon the submarine fan, and lateral shifts of the fans themselves.

Higgs (1988) interpreted the Honna Formation as a slope-apron fan complex, analogous to the Late Jurassic-Early Cretaceous Wollaston Forland Group of Greenland, interpreted as a slope-apron fan by Surlyk (1978). Higgs (1988) proposed that the Honna Formation was deposited in a peripheral foreland basin, located west of a series of west-verging thrust sheets. The "Sandspit thrust fault" acted as the sole thrust of this complex. A series of slope-apron fans were shed westward off the fault and into the mid-Cretaceous basin, overrunning the Haida shelf deposits. Slope-apron fans, as modelled by Surlyk (1978), are characterized by: a basinwards lateral coalescence of radial fans; a highly restricted to non-existent shelf; a voluminous and very coarse sediment supply shed from an adjacent fault block, against which the slope apron is built; and a series of alluvial fans shed from the fault block directly to the slope-apron fan. The inner part of the slope-apron fan is characterized by channelized conglomerates and sandstones, which grade basinwards into an outer fan complex composed of mudstone and fine sandstone.

Surlyk (1978) also indicated that paleocurrent trends within the Greenland slope apron fan were predominantly offshore-directed, but that the inner fan association featured trends which deviated up to 45° in either direction from this main trend (Fig. 5). This Surlyk (1978) attributed to the radial orientation of channels away from the apex of the fan, a feature typical of submarine fan systems in general (Walker, 1989).

The morphology of slope apron fans can easily be compared to that of alluvial fans. Alluvial fans form where streams confined by a narrow valley emerge onto a relatively unconfined plain (Rust and Koster, 1984). Flow expansion, and the resulting decrease in flow competency, leads to the rapid deposition of bedload. This forms a semiconical landform, with slopes and transport directions radiating from the mouth of the valley, or point source. Alluvial fans can coalesce laterally along a ridge, forming a bajada. The radial drainage pattern established upon the fan surface is reflected in the variability of channel orientations; one would expect to find a similar geometry established in the slope apron depositional environment.

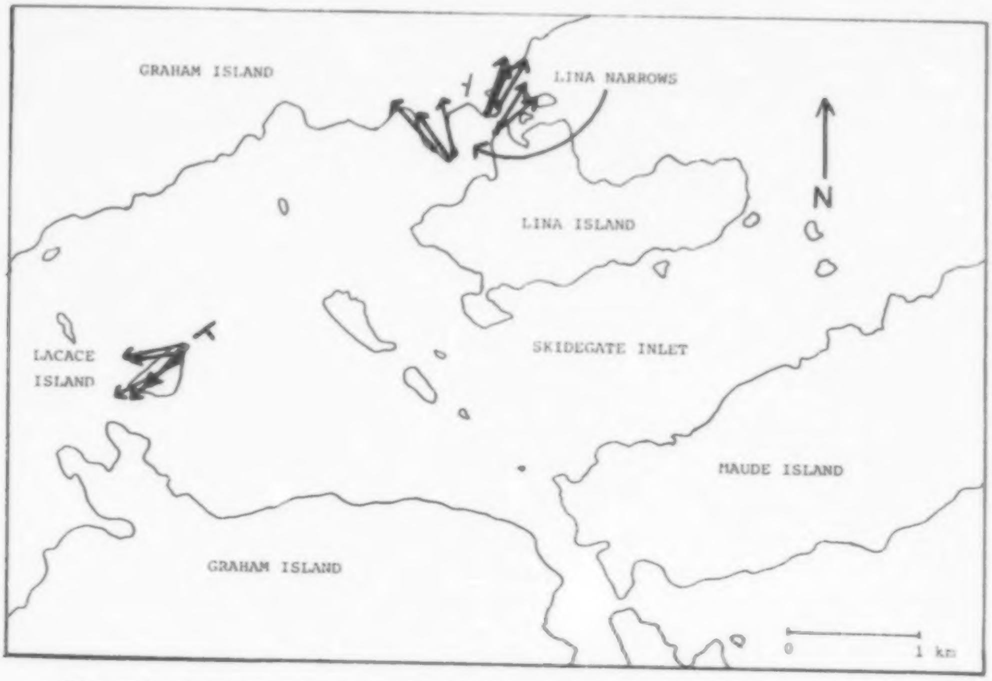

Figure 4. Paleocurrent trends within the Honna Formation, Skidegate Inlet area. Note counterclockwise shift in trend upsection at Lina Narrows.

Higgs' (1988) model of the Honna Formation differs somewhat from the slope-apron model of Surlyk (1978) in several other features as well. First, the existence of the Sandspit thrust fault, which Higgs (1988) cited as the main fault that controlled Honna deposition, was questioned by Thompson and Thorkelson (1989) based on their structural evidence indicating that the Rennell Sound Fault zone is a fold belt. Indeed, as Higgs (1988) noted, no known faults can positively be linked with Honna sedimentation. Second, there is no evidence for the existence of the extensive alluvial or deltaic belt that would be required to supply the fan system; rather, the Honna Formation is abruptly capped by outer shelf mudstones on northern and southern Graham Island. In addition, a large scale coarsening-upwards megasequence would be expected in the Honna Formation as rapid sedimentation quickly infilled the basin.

The variability in paleocurrent trends at the base of the Honna Formation indicates the existence of several distinct fan complexes which likely coalesced laterally along the slope of the mid-Cretaceous basin. Paleocurrent trends from the base of the Honna Formation do not appear to confirm the existence of a linear slope. Instead, the shelf-slope break within the basin appears to possess a complex geometry. The temporally correlative nature of the Skidegate Formation and the Haida shale member from east to west (Haggart, 1986) indicates that the basin deepened in a general westward direction. To date, no western margin for the basin has been delineated, suggesting that the basin may perhaps have opened westwards into the Pacific Ocean.

Vail et al. (1977) and Posamentier et al. (1988) have suggested that low stands in sea level commonly trigger the formation of submarine fans. According to global sea level charts of Vail et al. (1977), a eustatic sea level drop occurred in Early Coniacian time, which is correlative to the construction of the Honna fan. Alternatively, large scale block faulting during this time may have led to foundering of the shelf and the subsequent westward progradation of a submarine fan complex into the basin.

The coarse conglomeratic facies of the apron was likely flanked laterally by the fine grained and thinly bedded turbidites of the Skidegate Formation. Southward-directed paleocurrents within the Skidegate Formation in the Sewell Inlet area suggest that the locus of fan sedimentation shifted southwards with time.

The source area for the Honna conglomerates need not have been located within the Coast Mountains on the mainland, as proposed by Yagishita (1985) and preferred by Higgs (1988). We favour a local source, based on the presence of clasts derived from the underlying strata, particularly the Yakoun volcanics which comprise a large percentage of the clasts within the Honna Formation. Widespread Late Jurassic plutons of the Burnaby Island plutonic suite are scattered over Moresby and Graham islands (Anderson and Greig, 1989). This plutonic complex could extend offshore to the east, offering a local source of granitoid debris during Honna time.

CONCLUSIONS

The following conclusions regarding the Queen Charlotte Group can be made. (1) The fluvial deposits of the basal Haida sandstone member, described by Fogarassy (1989), are reinterpreted as marine deposits. (2) The Haida shale member is divisible into muddy shelf and slope deposits, with the slope oriented to the southwest. (3) The thinly bedded turbidites of the Skidegate Formation are interpreted as levee deposits, laterally adjacent to the channelized conglomerates of the fan. The Honna Formation is interpreted as the deposits of several, laterally adjacent submarine fan complexes. (4) Comparisons of Honna deposition with the slope-apron model of Surlyk (1978) are tenuous at best. Local variability in paleocurrent directions within the Honna Formation are interpreted as an inherent part of the depositional system and reflective of fan morphology,

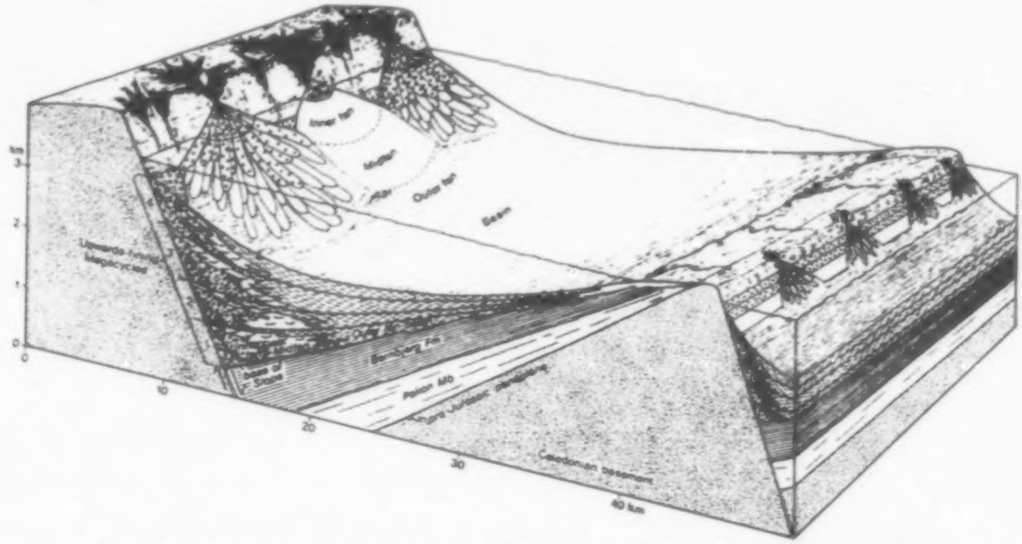

Figure 5. Slope-apron fan model of Surlyk (1978). Note radial orientation of channelized conglomerates in inner fan area.

rather than post-Honna deformation. (5) Initiation of submarine fan sedimentation was triggered by a relative drop in sea level, caused either by a eustatic sea level drop or an increase in the rate of sediment supplied to the basin related to uplift in the east. This led to the rapid westward progradation of a clastic wedge which effectively bypassed the Haida shelf.

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A progress report on the Pleistocene geology of Cape Ball, Graham Island, British Columbia[1]

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Fuller, E.A., A progress report on the Pleistocene geology of Cape Ball, Graham Island, British Columbia; in Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 75-82, 1990.

Abstract

A Pleistocene section in a sea cliff on Cape Ball contains two distinct diamictons. One, interpreted as till, is stone-rich with dominantly Queen Charlotte Islands (QCI) lithologies, has striated and faceted pebbles and a sandy silt matrix. The other, mapped as stony mud, is stone-poor with QCI lithologies, exotic metamorphic rocks, and sparse minute shell fragments, with striated and faceted pebbles and a clayey silt matrix. The till has generally well developed long axis pebble fabrics, indicating glacial flow to the northwest. The stony mud has long axis fabrics indicating flow to the northeast. The till is a local deposit from glaciers on the QCI. The stony mud is also a till, but it was deposited by a lobe of the Cordilleran Ice Sheet which crossed Hecate Strait and merged with the QCI glacier, causing northward deflection. The finer matrix and shell fragments represent entrainment of Hecate Strait deposits.

Résumé

Une coupe du Pléistocène, effectuée dans une falaise littorale au cap Ball, renferme deux diamictons distincts. L'un, qu'on interprète comme un till, est riche en pierres à lithologies surtout des îles de la Reine-Charlotte (IRC) et renferme des galets striés et à facettes ainsi qu'un ciment sableux et silteux. L'autre diamicton, cartographié comme une boue rocailleuse, est pauvre en pierres à lithologies des IRC, est constitué de roches métamorphiques exotiques de petits fragments rares de coquilles et renferme des galets striés et à facettes ainsi qu'un ciment de silt argileux. Le till présente généralement des fabriques de galets à axe bien marqué, indiquant un écoulement glaciaire vers le nord-ouest. La boue rocailleuse présente des fabriques à axe long indiquant un écoulement vers le nord-est. Le till est un dépôt local provenant de glaciers qui recouvraient l'archipel. La boue rocailleuse est également un till, mais elle a été déposée par un lobe de l'inlandsis de la Cordillère qui a traversé le détroit d'Hécate et qui a fusionné avec le glacier des IRC, le faisant dévier vers le nord. Les fragments de coquilles et le ciment à grain plus fin représentent un entraînement des dépôts du détroit d'Hécate.

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INTRODUCTION

This study was undertaken to examine and map Pleistocene deposits along the lower portion of sea cliffs on eastern Graham island in the Queen Charlotte Islands. The deposits studied are thought to be more than 50 000 years old based on radiocarbon dating (Clague et al., 1982). The maximum age of the sediments was unknown and an effort to date some of the fine grained members paleomagnetically was carried out on the structurally oldest deposits exposed at Cape Ball.

The purpose of the research was to determine the environments of deposition of diamictons at this key area where interaction between the Cordilleran Ice Sheet and a local Queen Charlotte Island glacier is postulated. Specific questions are: was the glacier grounded; where was detritus entrained by the glacier; and what were the local flow directions?

A grounded glacier condition can be inferred if lodgment till is present with associated boulder pavements, fluting, and stoss and lee relationships on clasts. A floating ice shelf or iceberg deposition may lead instead to homogenous diamicton without strong directional fabric (unless the water column beneath the ice is thin). Both cases may have occurred at Cape Ball during the Pleistocene.

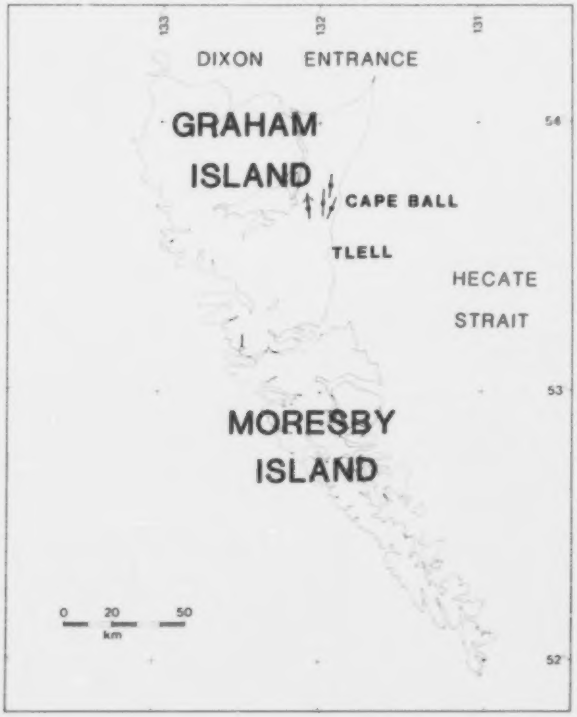

Figure 1. Location of Cape Ball sea cliffs on Graham Island, Queen Charlotte Islands. Regional ice flow directions of a local Queen Charlotte Islands ice sheet from flutings or drumlins. Definite north-flowing direction for one site (from Sutherland Brown, 1968).

Detritus transported by the glaciers will contain rock fragments from locally exposed bedrock and reworked clasts from surficial deposits. From the lithological composition of the pepples in diamictons provenance areas may be inferred.

To determine the character of glacier flow, a program of pebble fabric, striae, and structural geology measurement was undertaken. Evidence of deformation of the Cape Ball sediments has been known for some time (Sutherland Brown, 1968; Clague et al., 1982); however, the origin, direction of structures and their interrelationships have not been documented. This study serves to identify preliminary interpretations of structural features.

Previous geological study of the Cape Ball sections was carried out as part of the regional mapping of the Queen Charlotte Islands (Sutherland Brown, 1968; Sutherland Brown and Nasmith, 1962), and for paleoenvironmental purposes and regional sea level fluctuations (Warner et al., 1982; Clague et al., 1982); Warner, 1984.

The study originally involved mapping the lower 3 m of a 320 m long sea cliff at Cape Ball (Fig. 1) during the 1988 field season. In 1989 mapping was extended to an 850 m long stretch and up to the top of several sections at about 24 m (Fig. 2). The section is part of a much longer continuous sea cliff stretching from Cape Ball River to the bight north of Cape Ball. It is the thickest section along this part of the coast, extending up to 60 m above sea level.

DEPOSITIONAL UNITS

Four mappable units are exposed in the lower part of the sections (Fig. 3). Three facies are recognized.

Stony mud

Stony mud is a grey, heavily jointed stratum with sparse pebbles. The blocky and angular fracture pattern likely arises from desiccation on exposure to air. The silty clay matrix supports clasts which range in size from granules to boulders. Striations and faceted surfaces are present on some pebbles. The stony mud also contains minute fragments of white shell sporadically distributed within the silty matrix. Millimetre-scale lenses of fine sand form partings in the mud. These partings appear to mark shear planes within the generally massive unit.

Prominent stony mud within the section is referred to here as the middle stony mud. There are also an upper and a lower stony mud; all stony muds have similar characteristics.

Lodgment till

A tough indurated stone-rich diamicton is exposed near the base of much of the mapped section. It is distinguished from the stony mud by a brown hue, sandier texture, and crowded clasts. Several clasts within the till are faceted, striated, and supported by a silty sand matrix. The sandy matrix exhibits fissility as closely spaced parallel and sigmoidal structures.

Three separable tills occur in the section: a middle till, an upper till (or diamicton), and a lower till.

Figure 2. Sea cliff section at Cape Ball (718 m) showing diamicton at top underlain by well stratified sand (medium grey). Figure descending is at contact between light grey middle stony mud and dark grey bedded sand. Beneath the middle stony mud is a dark horizontally stratified sand underlain by medium grey till. The till (about 2 m thick) is underlain near the bottom of the photograph by lower stony mud with a cobble pavement at that contact. Total thickness of section is 12.5 m.

Subaqueous clastic sediments

Stratified sand and gravel make up a sorted clastic unit. Characteristic structures include planar crossbedding, graded bedding, and ripples. One prominent sand contains a compressed peat near its top.

DISCUSSION

The stony mud and till studied are diamictons. They are compared for matrix grain size, proportion of striated and faceted clasts, and proportion of pebble lithologies.

From preliminary granulometric analysis of a few specimens, the stony mud matrix is a clayey silt while the till matrix is sandy silt (Fig. 4). The muddier nature of the stony mud may have arisen from incorporation of fine sediment from Hecate Strait.

The proportion of striated and faceted clasts in the pebble fraction of four samples containing about 100 pebbles each from two till sites and two stony mud sites is presented (Fig. 5). The proportions overlap, indicating no preference for one unit to be more or less striated/faceted than the other. The average of striated pebbles is about 50 % with about 45 % faceted. A large proportion of the pebbles in both units are glacially transported.

The distribution of pebble lithologies for the four samples indicates a high proportion of volcanic rocks in each with more plutonic, metamorphic, and sedimentary rocks in the stony mud samples (Fig. 6). This suggests that the till is derived from local volcanic rocks exposed on Graham Island, and the stony mud is strongly influenced by the local geology but also carries far travelled metamorphic rocks, presumably from mainland British Columbia.

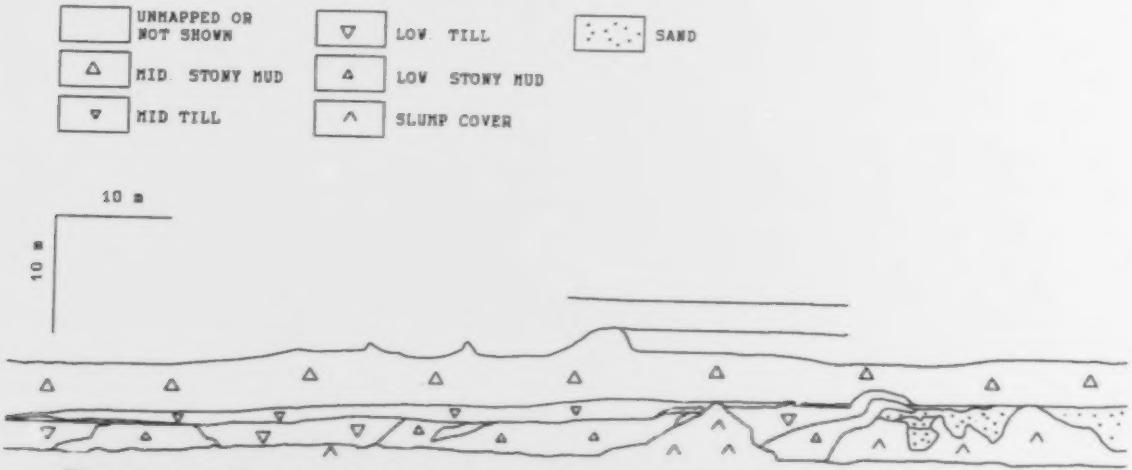

Figure 3. Lower portion of section from 0-96 m with slump cover at base. Lower stony mud is overlain by lower till in a complex fashion with middle till unit and middle stony mud unit above. Upper part of section is unmapped but consists of sand and an upper stony mud layer.

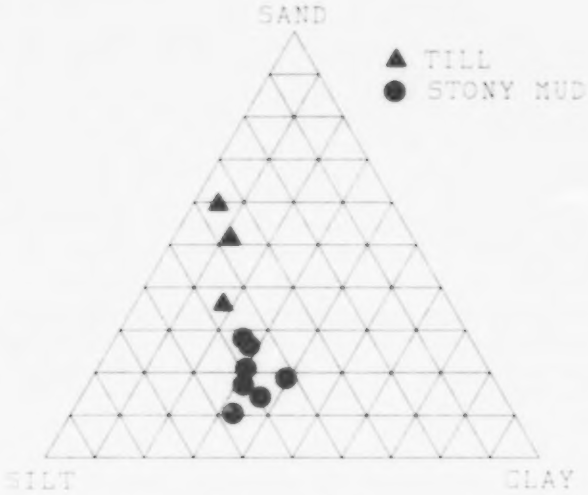

Figure 4. Ternary plot of sand-silt-clay proportions in stony mud and sandy silt till matrix samples from Cape Ball sections. Axes represent 100% composition of the less than 2 mm size fraction.

Pebble fabric

Pebble long axis of till and stony mud were measured along the section to determine the presence of fabric and fabric strength. Fourteen till fabrics are three stony mud fabrics are presented (Fig. 7, 8) with 20-52 individual pebble measurements per site. Contouring of the data shows concentrations or girdles on the lower net equal-area projections.

The till fabrics show a tendency for a unimodal or "smeared" unimodal pattern. Pebbles plunge at shallow angles to the southwest, south, and west and if imbricated would indicate glacial flow to the northeast, north, or east.

The three stony mud fabrics show gently southeast-plunging long axes and a northwest flow direction if imbricated with the same order of fabric as the till sites.

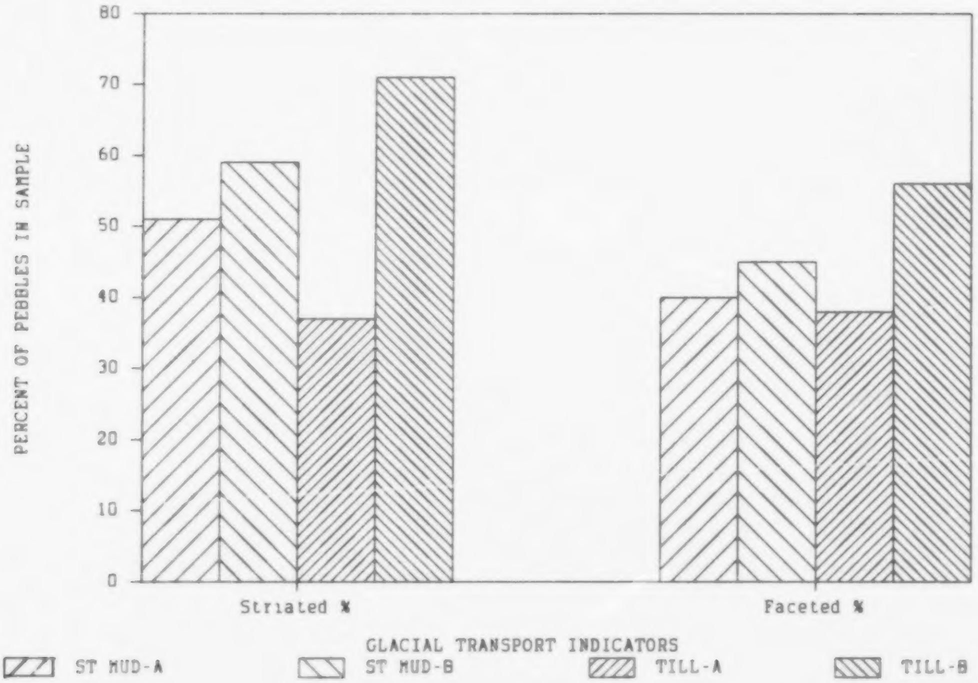

Figure 5. Proportions of pebbles with variations and faceted surfaces indicative of glacial transport for stony mud and till samples from Cape Ball sections (STONY MUD A, STONY MUD B, TILL A and TILL B).

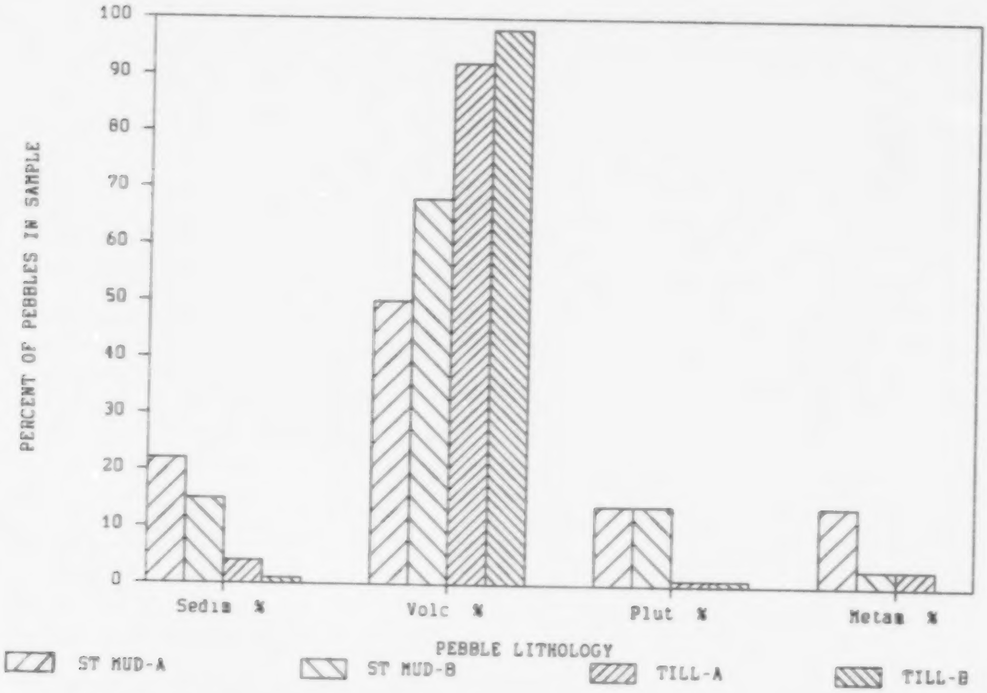

Figure 6. Pebble lithology proportions plotted for stony mud and sandy silt till samples from Cape Ball sections (same as in Fig. 5). A higher percentage of plutonic and metamorphic clasts in the stony mud suggests some of the clasts originated on the mainland while the sandy silt till is dominated by volcanic and sedimentary lithologies of local source areas on the Queen Charlotte Islands.

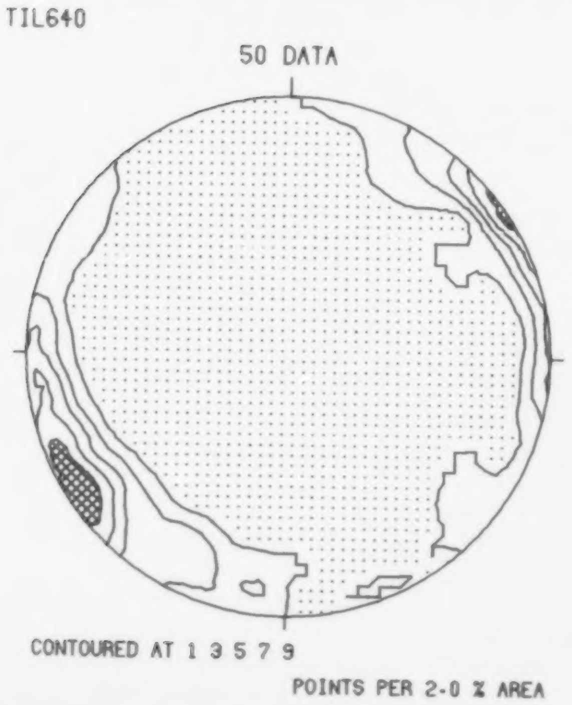

Figure 7. Contoured lower-hemisphere, equal-area long-axis fabric stereonet for sandy silt till at 640 m. Horizontal position is relative to a fixed datum at the south end of the Cape Ball section.

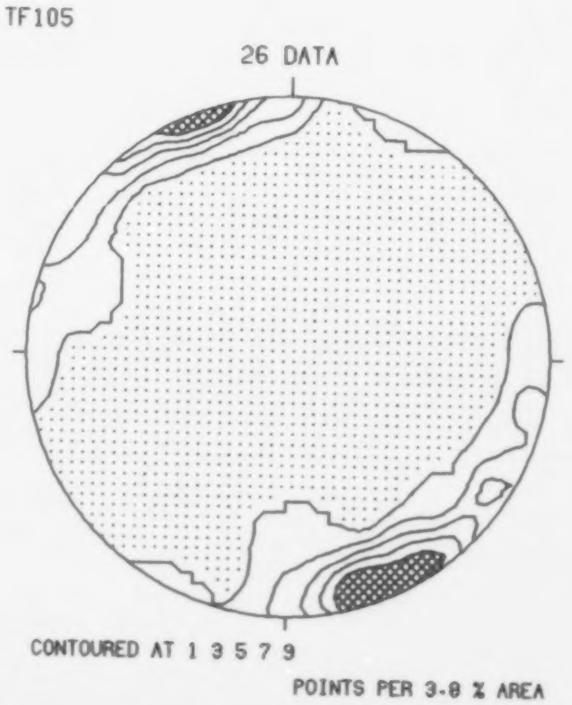

Figure 8. Contoured lower-hemisphere, equal-area, long-axis fabric stereonet for stony mud at 105 m. Horizontal position is relative to a fixed datum at the south end of the Cape Bell section.

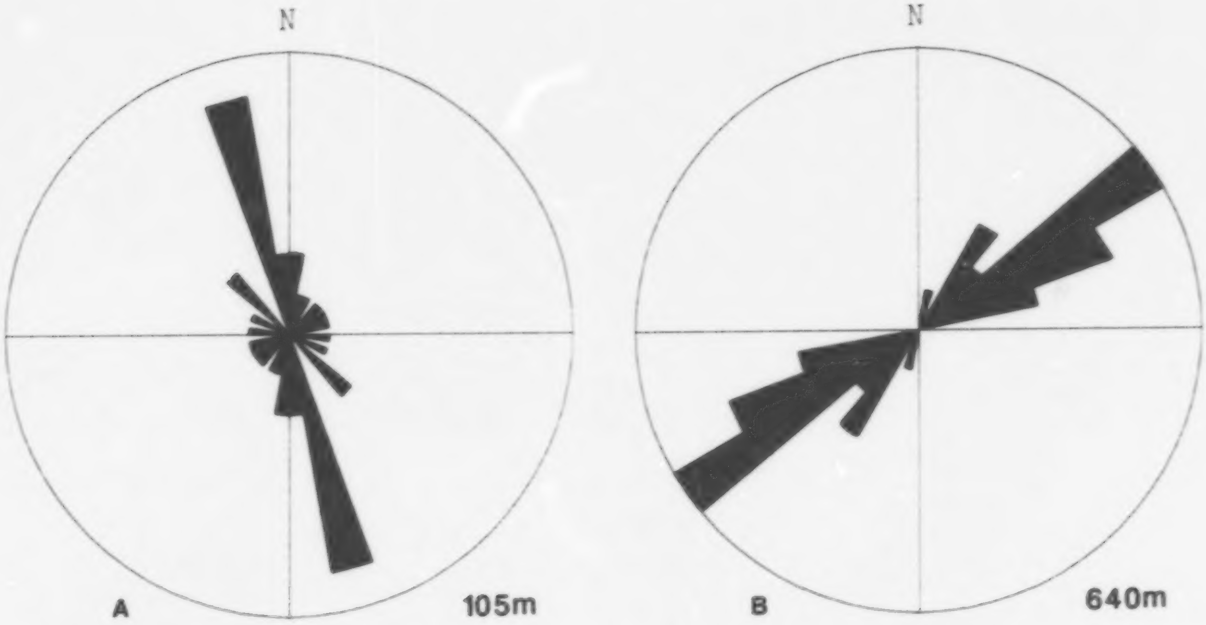

Figure 9. Mirror image rose diagrams of striae on stones from two sites. At one site (105 m), where data are from stony mud and underlying till, there is a strong north-northwest trend. At the second site (640 m), where data are from till only, the dominant trend is northeast. In both diagrams there are 21 azimuth measurements, the circle represents 7 measurements, and the interval class is 10%.

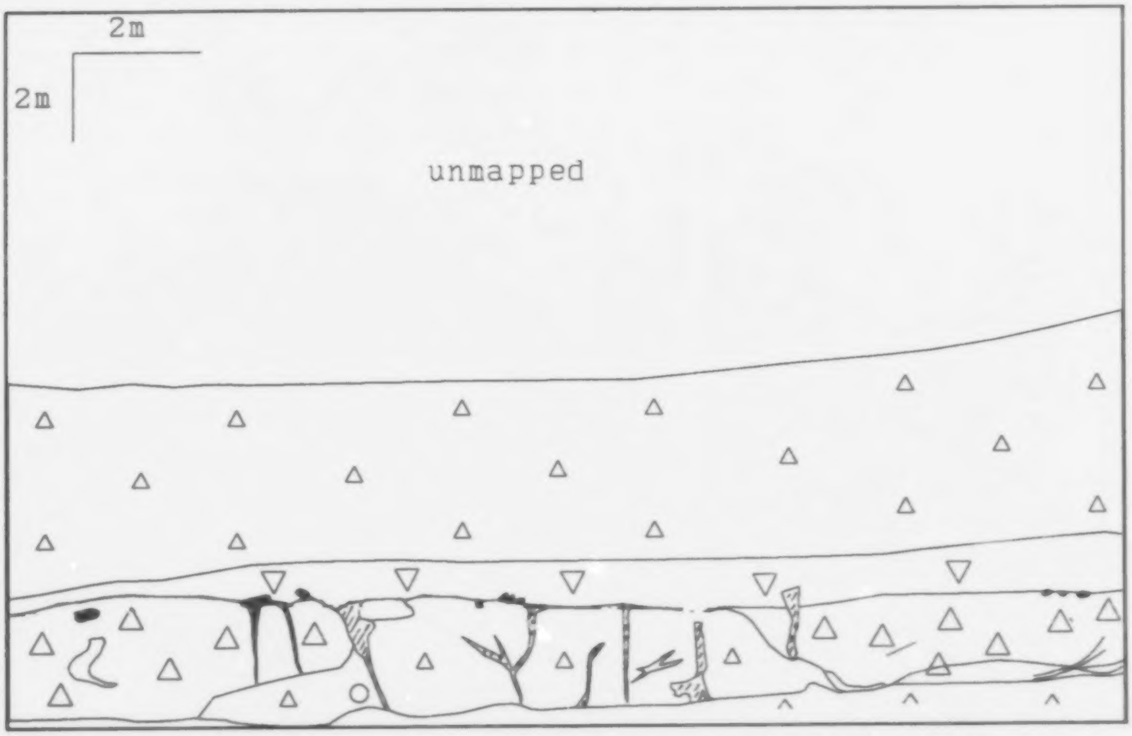

Figure 10. Cape Ball section (0-25 m) showing till and stony mud units (legend as in Fig. 3). Structures shown include: veins indicated by hatched pattern, shears as single curved lines, pavement cobbles greater than 20 cm as filled shapes, sample site stony mud A located at circle, hook fold in lower left corner.

Striations

Striations were measured on stones during fabric measurement and also from cobbles, particularly along stone pavements and at contacts between stony mud and lodgment till. Some measurements are grouped for seven sites and plotted as rose diagrams (Fig. 9) The data are plotted in two directions with a bin width of 10°. Although there is a scatter in directions for most of the sites, a few dominant trends can be observed. In site 105, which has till and stony mud fabrics for comparison, there is a dominant north-northwest trend corresponding to that in the mud and a weaker east-northeast trend which is barely recognizable in the till fabric. In this case the striae data were included for stones in mud and till immediately beneath the stony mud. At site 556, a multimode rose diagram compares to a till fabric from the same site. The striation data in site 600 were taken from the stony mud and give a strong northwest orientation while in the till unit at 640 there is a strong northeast striation development parallel to the till fabric at that point.

Structures

The structures found in the stony mud and till at Cape Ball include: stone pavements, veins, shears, folds, stoss and lee indicators, and channelling at the outcrop scale (Fig. 10). The most evident feature of these is the presence of two cobble pavements: one at the interface between a till and the middle stony mud above it, the other at the top of a lower stony mud and the base of the same till (Fig. 11,12). Many of the tops of stones are faceted and striated. Striae directions correspond to till deposited by glacier ice flowing northwest and stony mud deposited by glacier ice flowing northwest.

Evidence of high pressure contained flow is present at two sites. At one site (468 m) were four parallel channels, 20-45 cm wide and 10-15 cm deep, cut into the middle stony mud and filled with sand. The top of the mud appears planed off and includes two small potholes. The channels themselves have oversteepened sides and finger-like interior

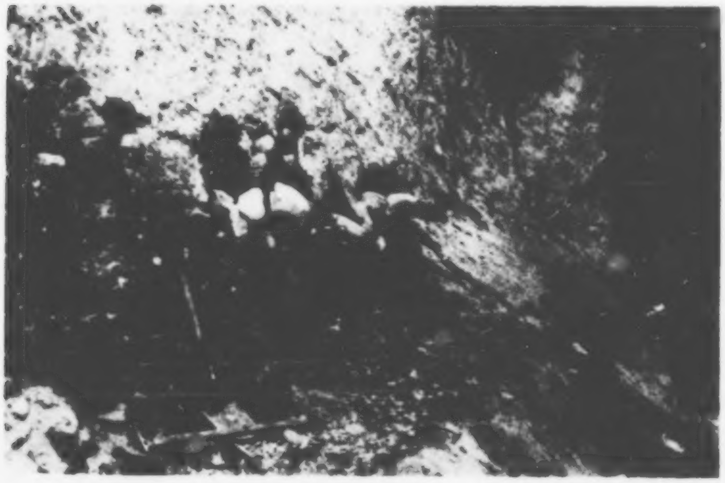

Figure 11. Stone pavement at the base ot the middle till unit and overlying the lower stony mud unit (696 m). Striations indicate dominant northeast flow presumably related to overlying till.

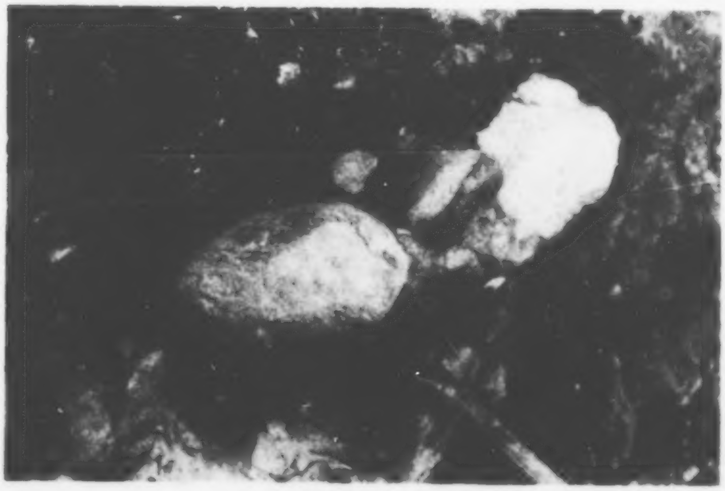

Figure 12. Close-up view of faceted and striated cobbles at the stone pavement between the lower stony mud and middle till (682 m). The sense of glacier flow is from left to right based upon stross and lee relationships and in the northeast direction.

subchannels. The channel axes trend at 315° — the same as glacial flow. Subglacial meltwater flow may have followed the glacial flow direction. At the second site small channels are cut into an inclined stony mud surface.

CONCLUSIONS

Comparisons of parameters for two diamicton types at Cape Ball Pleistocene sections suggests that stony mud and till were deposited by grounded glacier ice. Hence both can be considered as till. The differences in grain size and pebble lithologies stem from differences in the source areas; the till, deposited by local glaciers on the Queen Charlotte Islands was derived from Mesozoic volcanic rocks, and the stony mud was derived from mainland British Columbia about 100 km to the east hand has incorporated metamorphic rocks from outcrops on the mainland and muddy deposits and shell material from the floor of Hecate Strait. Differences in ice flow directions may have resulted in competition between these two glaciers which merged and followed a northerly path. Northeast flow deposited the till as Queen Charlotte Islands ice pushed into Hecate Strait; northwest flow of the Cordilleran Ice Sheet characterizes the other till.

Cobble pavements formed at the contact between till and overlying stony mud, with northwest-trending top striations and channels cut at the top of stony mud with similar orientation point to a subglacial depositional environment for the stony mud.

ACKNOWLEDGMENTS

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A progress report on late Quaternary benthic foraminifera from the central continental shelf of western Canada[1]

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Patterson, R.T., A progress report on late Quaternary benthic foraminifera from the central continental shelf of western Canada; in Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 83-86, 1990.

Abstract

This ongoing study contributes to deciphering the paleogeography of the western shelf of Canada and the understanding of the potential hazards to offshore hydrocarbon exploration. Preliminary qualitative analysis of 39 samples extracted from 4 piston cores and 1 vibro-core has yielded a fauna of 95 species of benthic foraminifera. One of these species, ***Nanosylvanella palmulina*** *Patterson, is new and not referable to any previously described genus.*

Résumé

Cette étude donnée à contrat permettra de mieux comprendre la paléogéographie de la plate-forme occidentale du Canada ainsi que les risques possibles de l'exploration des hydrocarbures en mer. L'analyse qualitative préliminaire de 39 échantillons procurant de quatre carottes prélevées par carottier à piston et par vibrocarottier a fourni une faune de 95 espèces de foraminifères benthiques. Une de ces espèces, ***Nanosylvanella palmulina*** *Patterson, est nouvelle et n'appartient à aucun des genres déjà décrits.*

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INTRODUCTION

Queen Charlotte Sound and Hecate Strait (Fig. 1) are part of the Hecate Depression (Holland, 1964). This basin is of considerable importance, not only for its potential hydrocarbon reserves, but also for clues it can offer about the Quaternary paleoceanographic history of the west coast of Canada.

In the 1960s a series of onshore and offshore exploration wells were drilled in Queen Charlotte Sound and Hecate Strait into the underlying Neogene Queen Charlotte Basin. After an almost 20 year hiatus, renewed oil industry interest in the area has sparked a major research programme aimed at a better understanding of the Neogene depositional history of the basin and identification of potential hazards to hydrocarbon exploration. Patterson (in press A) has completed a biostratigraphic and paleoecological examination of benthic and planktonic foraminifera from the southern part of the basin. This complements other paleontological, seismic, and sedimentological research being carried out in the area.

The purpose of the present research is to carry out a high resolution analysis of foraminiferal faunas found in Quaternary core samples from the Queen Charlotte Sound-southern Hecate Strait area. Foraminiferal assemblages are useful in recognizing temperature and salinity changes expected in water masses during glaciation and deglaciation. The foraminiferal distributional data coupled with sedimentological and geochronological results (Luternauer et al., 1989a, b) will be used to determine paleoenviromental conditions during Quaternary deposition at these sites. Qualitative and quantitative analysis of benthic foraminifera from closely spaced samples from these cores should provide corroborative evidence for suspected rapid water depth changes accompanying a regression at about 13-11 ka and a subsequent (ca. 10-9 ka) transgression, as indicated by the sedimentological studies. Knowledge of the sea level history is essential to the rigorous interpretation of offshore geohazards to hydrocarbon exploration. Finally, as there has never been an examination of Quaternary foraminifera from this area, this research will provide a valuable baseline on foraminiferal distribution and ecology for future researchers.

PREVIOUS WORK

Very few published studies on Holocene (Recent) shelf foraminifera, and only two studies of Pleistocene foraminifera (Smith, 1970, 1978) have been published for the coast of British Columbia. Patterson has completed contracted studies for the Geological Survey of Canada on the

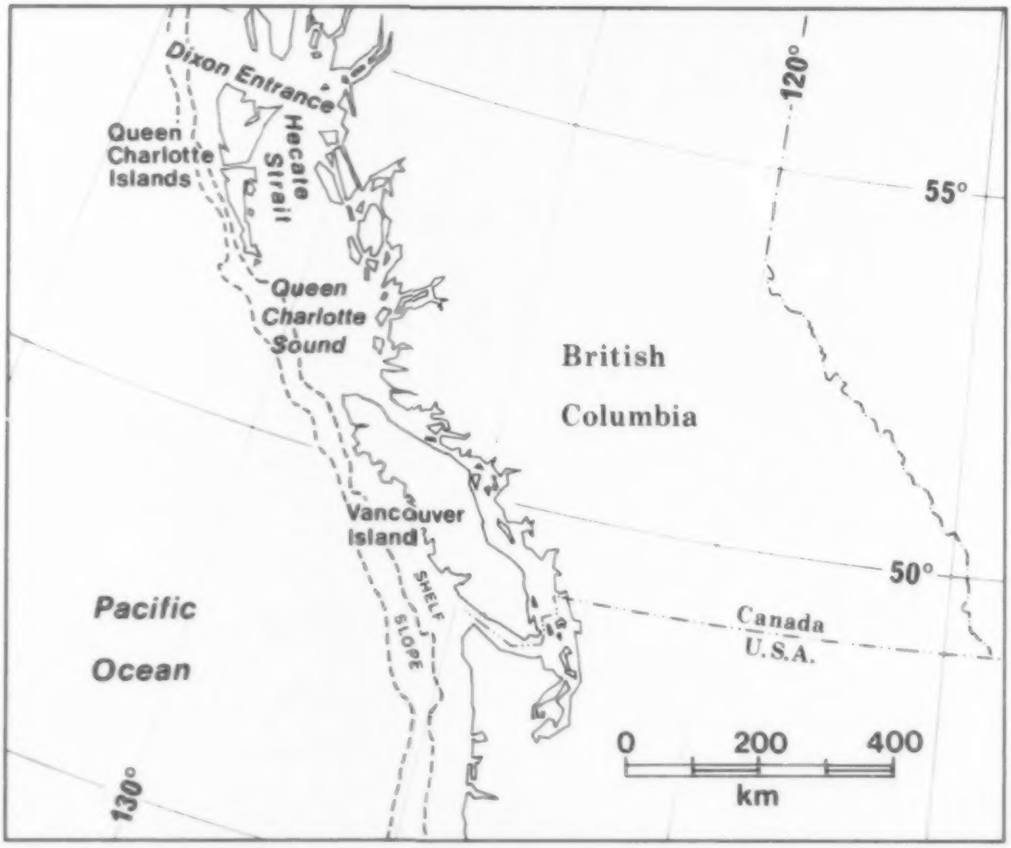
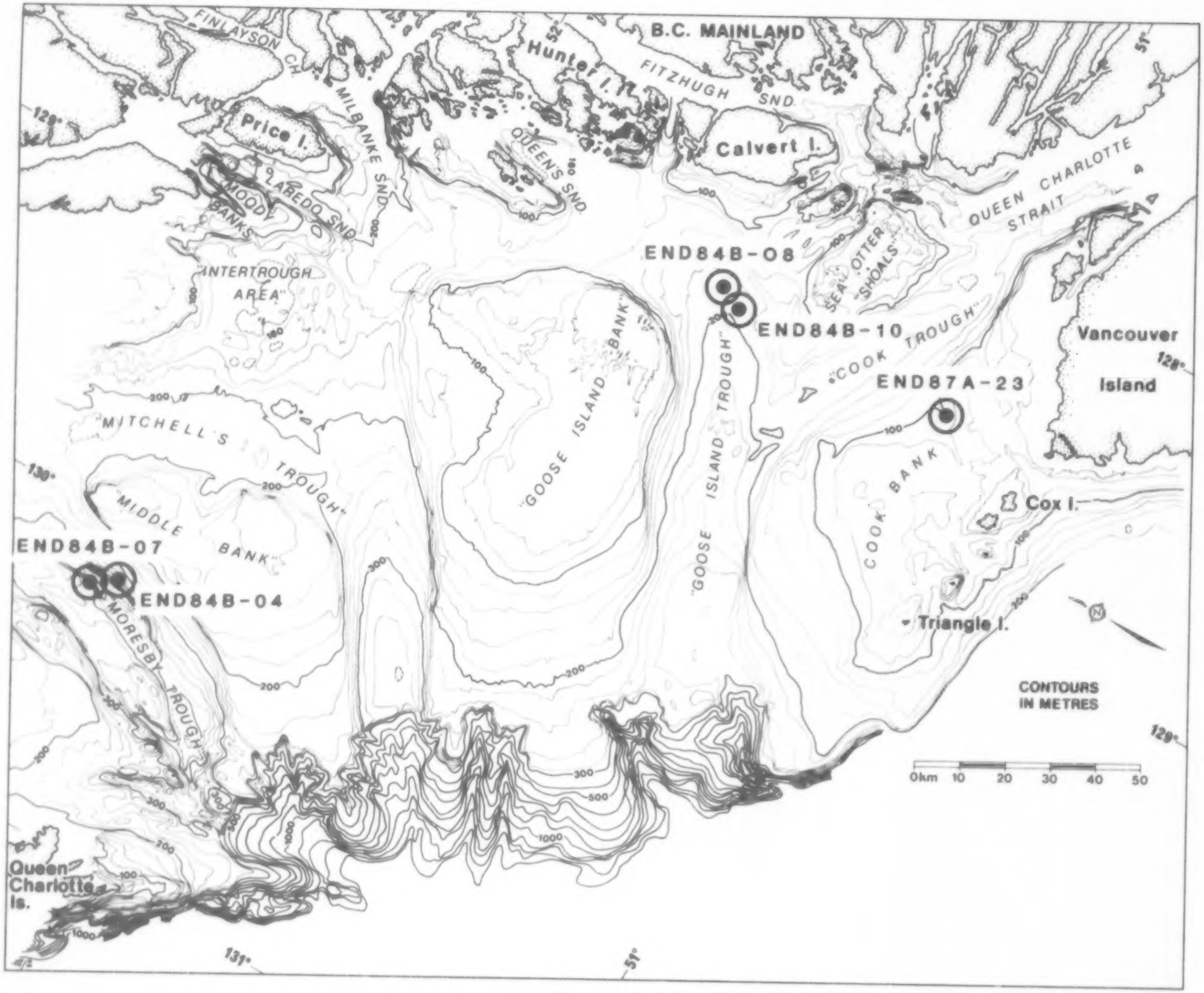


Figure 1. Major geographic areas of the western coast of Canada.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"INTERTROUGH AREA"
END84B-08
END84B-10
"SEA OTTER SHOALS"
"GOOSE ISLAND BANK"
"GOOSE ISLAND TROUGH"
"COOK TROUGH"
END87A-23
Vancouver Island
"MITCHELL'S TROUGH"
"MIDDLE BANK"
COOK BANK
Cox I.
END84B-07
END84B-04
MORESBY TROUGH
Triangle I.
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Queen Charlotte Is.
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10
20
30
40
50
128°
129°
130°
131°
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52°
100
200
300
500
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Figure 2. Bathymetric map of Queen Charlotte Sound-southern Hecate Strait showing location of cores from which Late Quaternary benthic foraminifera are being studied.

Late Quaternary foraminifera of the Fraser River delta. Cushman (1925) described a few species found in shallow waters (14-45 m) in Virago and Queen Charlotte sounds. Cushman and Todd (1947) described the Holocene fauna from coastal areas of the state of Washington near the British Columbia border. An another systematic treatment, McCulloch (1977) illustrated a few taxa collected from three stations surrounding Vancouver Harbour. Cockbain (1963) conducted a distributional study of foraminifera from depths of 112-293 m in the Strait of Georgia. As part of a cursory examination of marsh foraminiferal faunas along the Pacific coast of North America, Phleger (1967) analyzed samples from several localities in British Columbia, including the Fraser Delta. Gallagher (1979) documented the distribution of Holocene foraminifera from the continental shelf and slope of Vancouver Island. The most recent foraminiferal studies from the region have been detailed analyses of marsh foraminiferal biofacies from the Fraser Delta (Williams, in press).

METHODS AND MATERIALS

Thirty-nine samples were obtained from 4 piston cores and one vibro-core collected by the Geological Survey of Canada from Queen Charlotte Sound (Fig. 2). Sampled intervals correspond to marine sedimentary units described in Luternauer et al. (1989a, b) Locations of cores are:
Core END 87A-23, 50°59.94′N, 128°25.55′W
Core END 84B-04, 52°14.72′N, 130°09.05′W
Core END 84B-07, 52°16.70′N, 130°12.27′W
Core END 84B-08, 51°31.07′N, 128°23.11′W
Core END 84B-10, 51°28.14′N, 128°25.14′W.

All samples were boiled with soda ash to cleanse the foraminiferal tests for examination. Samples were then rinsed using 63 micron screens to retain the foraminifera. Samples containing large amounts of sand were dried, and the foraminifera separated from the sand by floatation in sodium polytungstate (SG=2.28).

RESULTS AND INTERPRETATION

Quantitative analysis of these samples is in the most preliminary stage, thus no paleoenvironmental analysis based on foraminiferal distribution can yet be made. Ninety-seven foraminiferal species have thus far been identified and fully illustrated with a scanning electron microscope. As the foraminiferal faunas found off the west coast are almost unknown, I am also preparing an atlas of the foraminifera found in British Columbia waters. The need for systematic study of these foraminifera is underlined by the discovery of a new genus and species of calcareous unilocular foraminifera, **Nanosylvanella palmulina** Patterson (Patterson, in press B).

ACKNOWLEDGMENTS

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Petroleum source rock characteristics of the Tertiary Skonun Formation, Queen Charlotte Islands, Hecate Strait and Queen Charlotte Sound, British Columbia[1]

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Bustin, R.M., Vellutini, D., and Goodarzi, F., Petroleum source rock characteristics of the Tertiary Skonun Formation, Queen Charlotte Islands, Hecate Strait and Queen Charlotte Sound, British Columbia; in Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 87-93, 1990.

Abstract

The Neogene Skonun Formation comprises more than 4500 m of nonmarine and transitional marine strata. On Graham Island the formation is mainly immature with respect to oil generation, whereas in Hecate Strait and Queen Charlotte Sound the formation varies from immature to overmature. The source rock potential of the strata is probably poor to moderate. In general, the organic matter is gas prone Type II or Type III with low hydrogen and production indices. Locally, there are intervals with Type I or Type II organic matter, with hydrogen indices up to 450 mg HC/g TOC, production indices up to 1.0, and with quality of organic matter values up to 6 mg HC/g rock. There is no apparent stratigraphic or lateral variation in source rock quality. In general, total organic carbon contents are higher on Graham Island and in northern Hecate Strait than in Queen Charlotte Sound.

Résumé

La formation néogène de Skonun renferme plus de 4500 m de couches non marines et de couches marines de transition. Dans l'île Graham, la formation est surtout immature quant à la production de pétrole, alors que dans le détroit d'Hécate et le bassin Reine-Charlotte la formation varie d'immature à surmature. Les possibilités de roches mères des couches sont probablement médiocres à modérées. En général, la matière organique est à potentiel gazifère de type II ou de type III à faibles indices d'hydrogène et de production. Il existe par endroits, des intervalles contenant de la matière organique de type I ou de type II, à indices d'hydrogène atteignant 450 mg HC/g de carbone organique total et avec une qualité des valeurs de matières organiques atteignant 6 mg HC/g de roche. Il n'existe aucune variation stratigraphique ou latérale apparente de la qualité de la roche mère. En général, les teneurs en carbone organique total sont plus élevées dans l'île Graham et dans la partie nord du détroit d'Hécate que dans le bassin Reine-Charlotte.

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INTRODUCTION

The Neogene Skonun Formation (Sutherland Brown, 1968; Higgs, 1989) comprises a thick succession of interbedded marine and nonmarine clastic strata at least 5 km thick. The formation outcrops on or underlies a thin veneer of Quaternary sediments on eastern Graham Island and extends offshore beneath Hecate Strait and Queen Charlotte Sound (Shouldice, 1973; Yorath and Hyndman, 1983). The Skonun Formation has generally been considered both the most promising hydrocarbon reservoir and source rock in the Queen Charlotte Islands and adjacent offshore areas. Fourteen exploratory drillholes tested the onshore and offshore succession during the 1950s and 1960s, none of which encountered significant hydrocarbon accumulations (Fig. 1).

The levels of organic maturation of surface and subsurface samples from Graham Island were described by Vellutini and Bustin (1988, 1990). As part of a study to evaluate the level of organic maturation and source rock potential of the Phanerozoic succession in the Queen Charlotte Islands, surface exposures on Graham Island and core and well cuttings from the exploratory drillholes were sampled. The degree of organic maturation was determined by vitrinite reflectance following usual methods (Bustin et al., 1985). Rock-Eval pyrolysis and total organic carbon analyses were performed using the procedures of Espitalie et al. (1977). This report gives preliminary results obtained from Rock-Eval pyrolysis, total organic carbon (TOC) analyses, and vitrinite reflectance of organic matter from these samples.

RESULTS

Representative results of Rock-Eval pyrolysis and total organic carbon (TOC) analyses of samples obtained from two onshore and two offshore exploratory wells are shown in Figures 2 through 5. The onshore strata comprise a nonmarine and transitional marine succession of interbedded sandstone, siltstone, shale, and thin coals. The strata include primarily Type III and minor Type II organic matter with moderate gas potential and no to poor oil potential. The quality of the organic matter (QOM) ranges up to 2.2 mg HC/g rock, the hydrogen index (HI) varies from about 65 to 180 mg HC/g TOC and the production index (PI) varies from 0.1-1. Based on results obtained to date there is no apparent lateral or stratigraphic variation in abundance nor quality of the organic matter. In outcrop and in the onshore exploratory drillholes the Skonun Formation is immature with respect to the oil window, except for the basal part of the Tow Hill well and the Port Louis well (Vellutini and Bustin, 1988). The higher maturation values in the Tow Hill well and the Port Louis wells (up to 1.1 % mean random vitrinite reflectance) reflect deeper burial and higher heat flow (Vellutini and Bustin, 1990).

Offshore the Skonun Formation comprises a succession of marine, transitional marine, and nonmarine clastic rocks including thin coal seams likely significantly more than 4.5 km thick (Shouldice, 1973). Correlations between exploratory boreholes cannot be made on lithology alone, and the strata were likely deposited in a series of sub-basins. Preliminary interpretations indicate that the organic matter

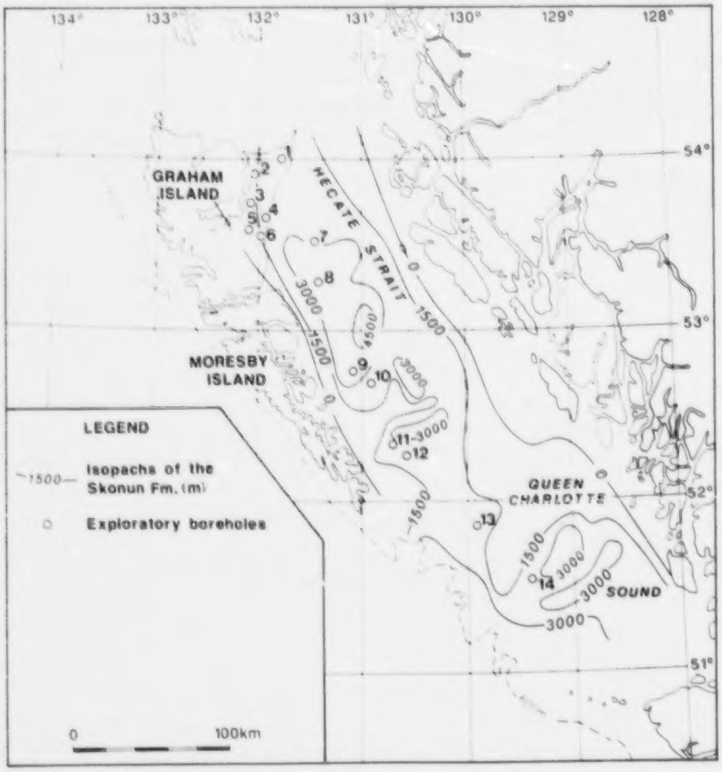

Figure 1. Index map to the study area showing location of exploratory boreholes utilized in this study. Isopachs of the Skonun Formation from Shouldice (1973). Boreholes: 1-Tow Hill; 2-Masset; 3-Nadu River; 4-Cape Ball; 5-Gold Creek; 6-Tlell; 7-South Coho I-74; 8-Tyee M-39; 9-Sockeye B10; 10-Sockeye E-66; 11-Murrelet L-15; 12-Auklet G-41; 13-Harlequin D-86; 14-Osprey D-36. Modified from Higgs (1988).

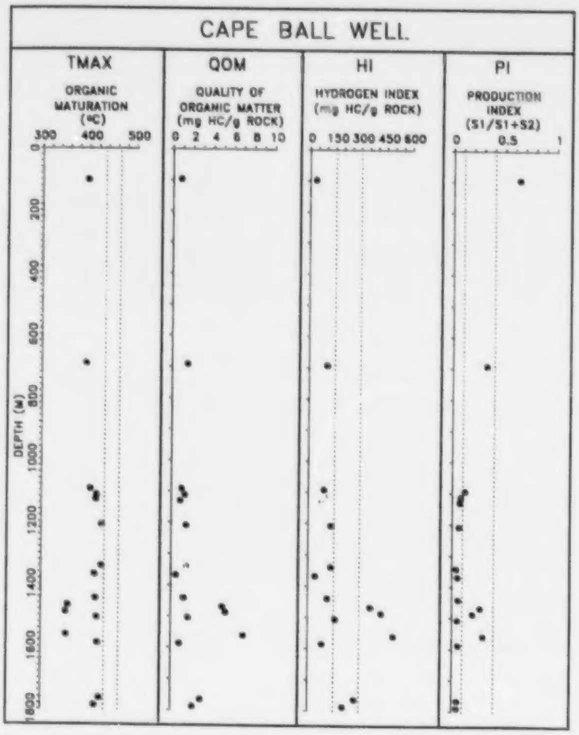

Figure 2a. Rock-Eval logs for the Cape Ball well. Quality of organic matter (QOM) = (S1 + S2)/TOC; hydrogen index (HI) = S2/TOC; PI = production index. Dashed lines in Tmax log represent the oil window. Refer to Figure 1 for well location.

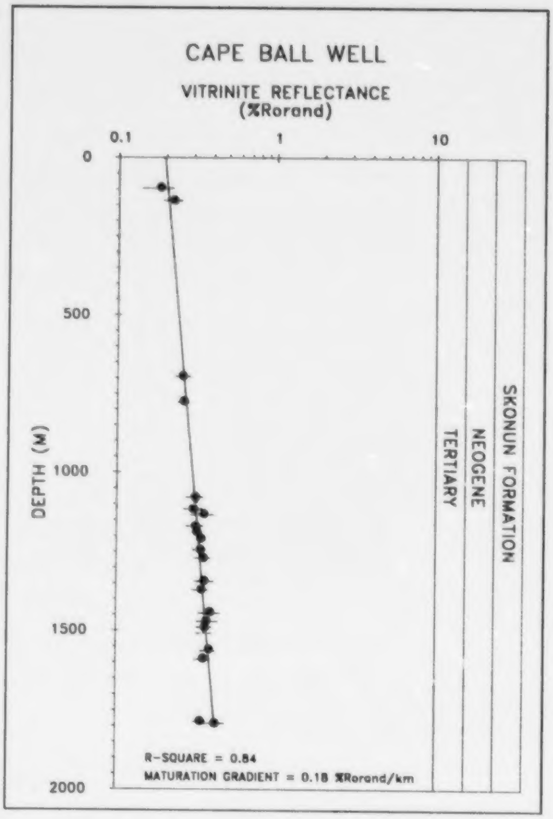

Figure 2b. Mean random vitrinite reflectance vs. depth for the Skonun Formation, Cape Ball well.

is mainly gas-prone Type III and Type II. Thick intervals containing significant amounts of oil-prone Type I and Type II organic matter are locally present, with HI values up to 450 mg HC/g TOC (Fig. 4 and 5). The QOM reaches 10 mg HC/g rock and PI reaches 1. The abundance of the organic matter is similarly variable; much of the penetrated succession has TOC values less than 1 % although intervals with values exceeding 2 % are common. There is no readily apparent stratigraphic variation in abundance and quality of organic matter in and between the offshore wells. In general, the average TOC content is higher in the Skonun Formation in the northern part of Hecate Strait compared with Queen Charlotte Sound to the south. The high TOC values in the north reflect the greater abundance of carbonaceous partings and coal.

The level of organic maturation of the offshore strata is highly variable. Based on preliminary vitrinite reflectance analyses and interpretation of Tmax data from Rock-Eval pyrolysis (Fig. 4 and 5), all the offshore exploratory wells include thick sequences within the oil window (Tmax values from 435-465°C).

CONCLUSIONS

Preliminary results indicate that the Skonun Formation on Graham Island is primarily immature, whereas offshore the formation ranges from immature to overmature with respect to the oil window. The TOC content is highly variable; the highest TOC intervals correspond to strata with carbonaceous partings or discrete coal seams. The quality of the organic matter as measured by Rock-Eval pyrolysis is similarly variable. Most intervals are composed of gas prone Type II and Type III organic matter with low HI, QOM, and PI values. Locally, intervals containing significant quantities of oil and gas prone Type II and Type III organic matter occur with HI values up to 450 mg HC/g TOC and QOM values to 10 mg HC/g rock.

Future studies will more fully integrate the source rock quality with the biostratigraphic and lithostratigraphic studies in progress by James White and Roger Higgs. Additional vitrinite reflectance and organic petrographic studies currently underway will define the lateral and stratigraphic variation in organic maturation of the offshore strata and provide a data base for modelling the thermal history of the Queen Charlotte Islands, Hecate Strait and Queen Charlotte Sound.

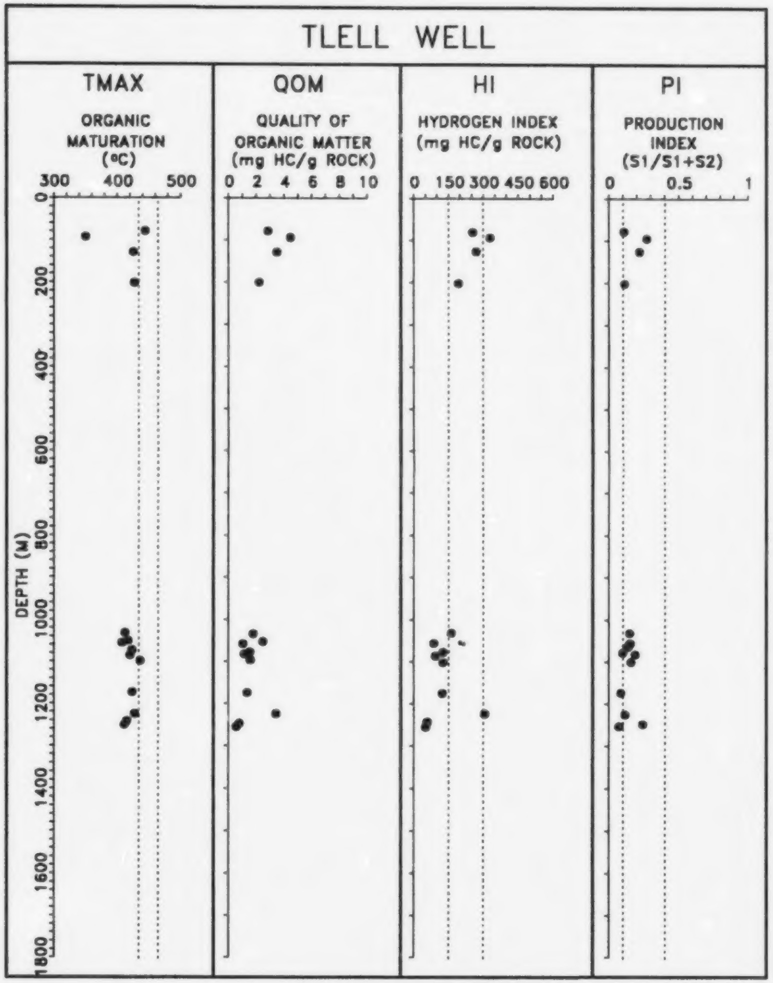

Figure 3a. Rock-Eval logs for the Tlell well. Quality of organic matter (QOM) = (S1 + S2)/TOC; hydrogen index (HI) = S2/TOC; PI = production index. Dashed lines in Tmax log represent the oil window. Refer to Figure 1 for well location.

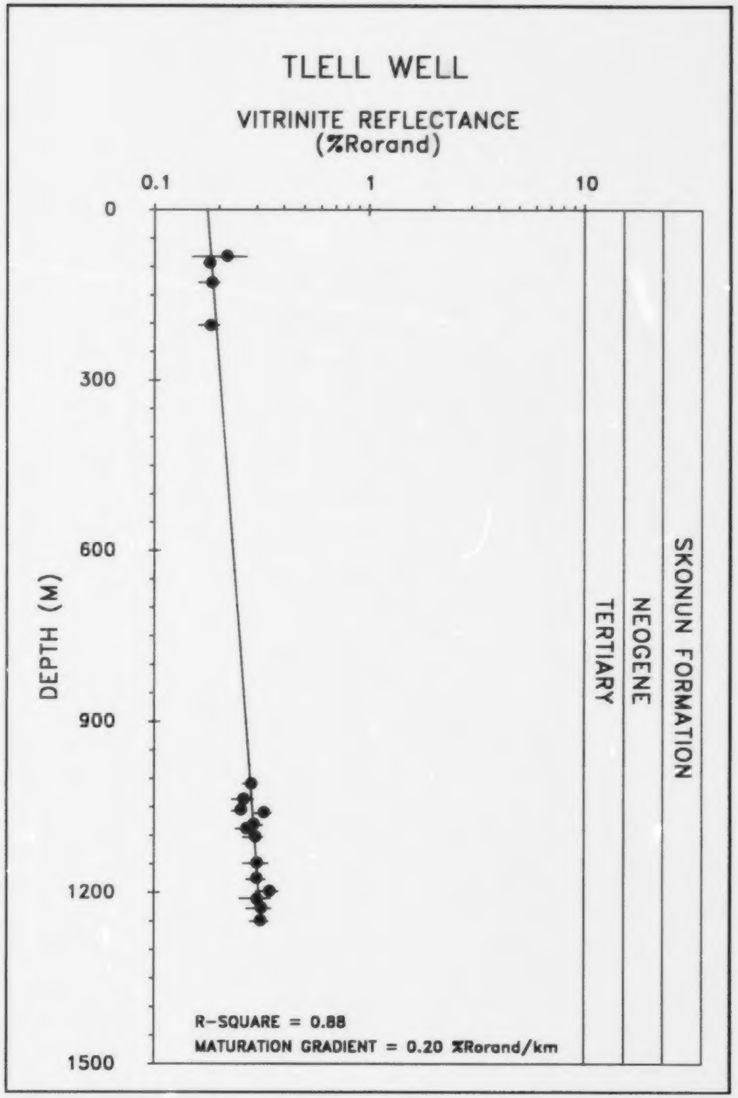

Figure 3b. Mean random vitrinite reflectance vs. depth for the Skonun Formation, Tlell well.

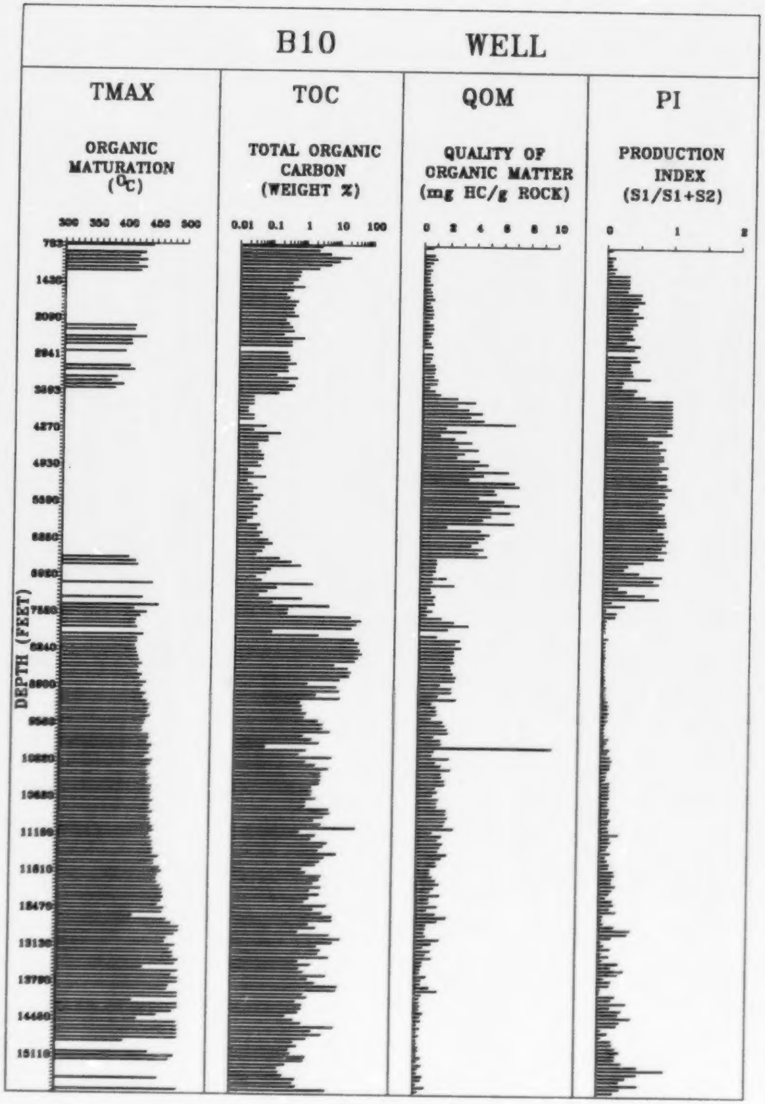

Figure 4a. Rock-Eval logs for the Sockeye B-10 well. Quality of organic matter (QOM) = (S1 + S2)/TOC. Refer to Figure 1 for well location.

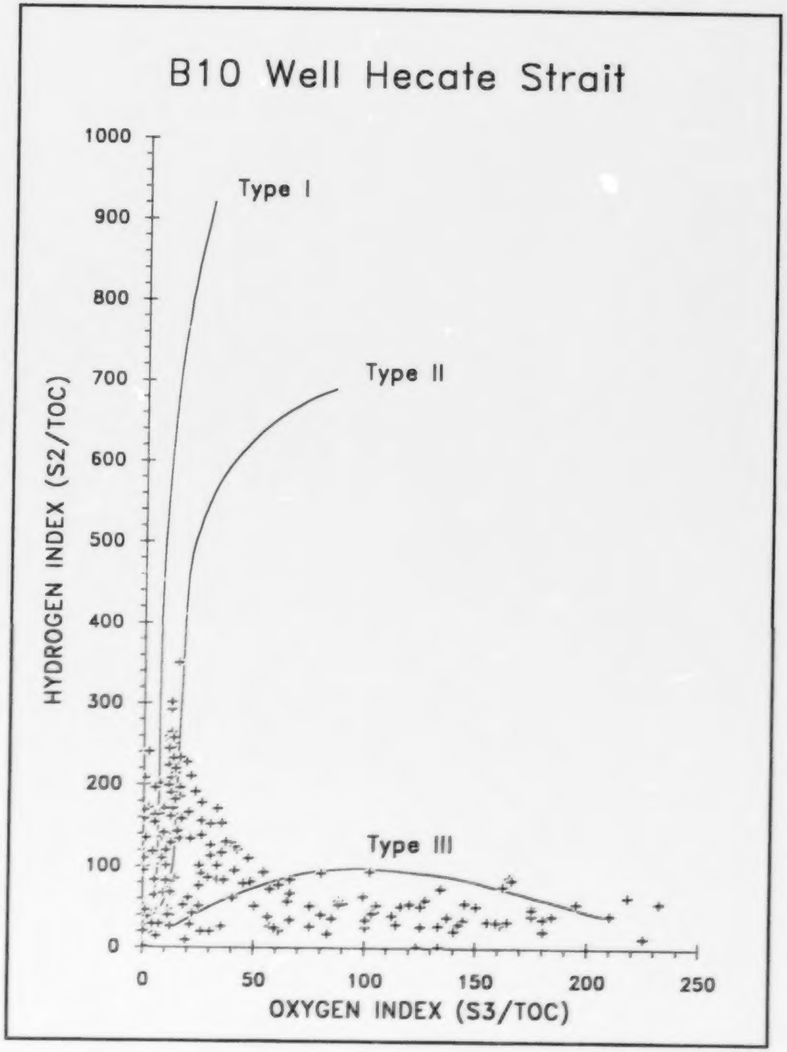

Figure 4b. Hydrogen index vs. oxygen index for samples from the Sockeye B-10 well. Diagenetic pathways for the three main kerogen types are shown.

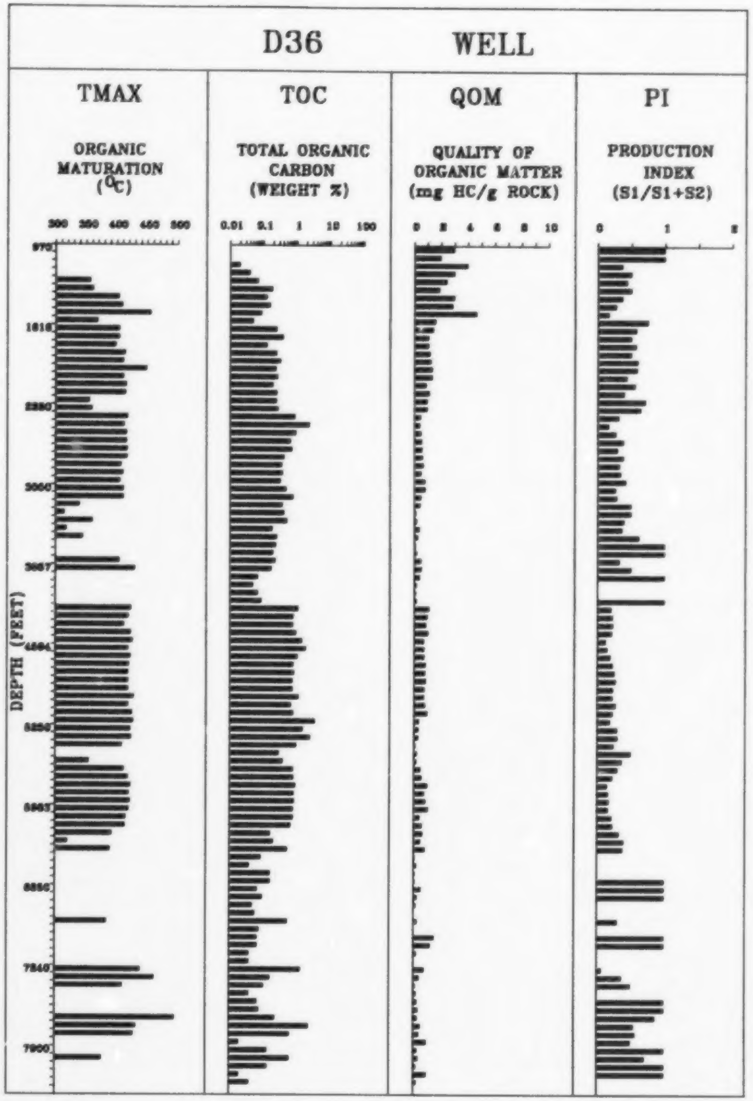

Figure 5a. Rock-Eval logs for the Osprey D-36 well. Quality of organic matter (QOM) = (S1 + S2)/TOC. Refer to Figure 1 for well location.

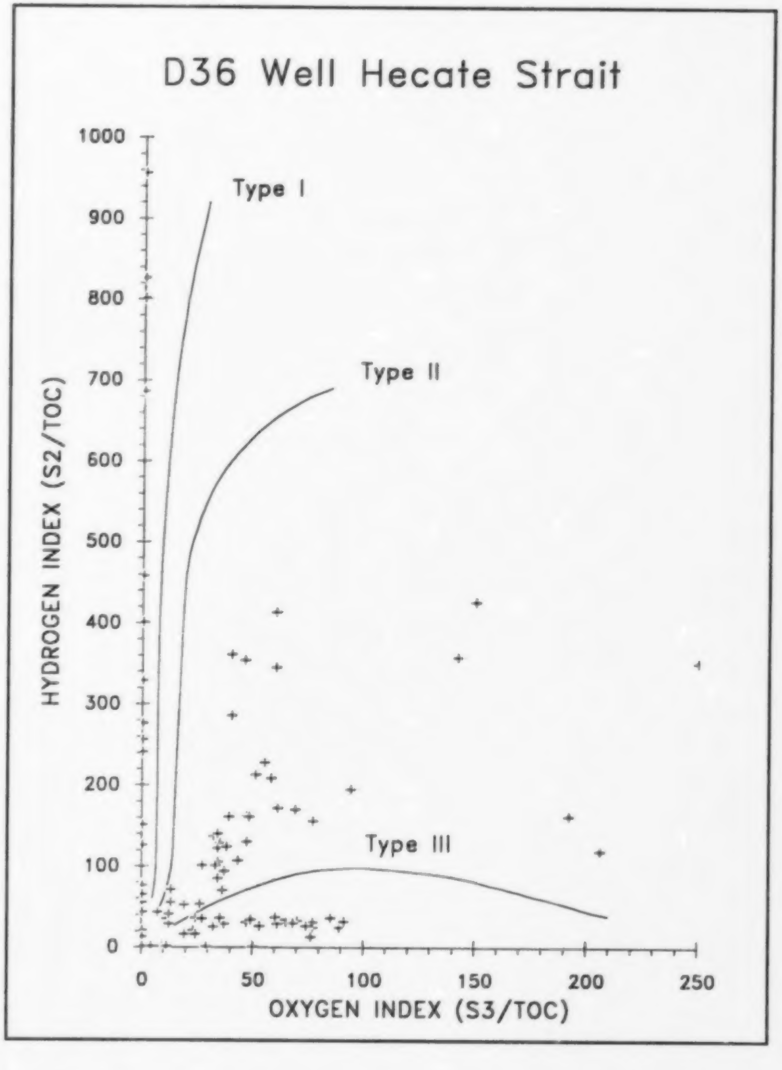

Figure 5b. Hydrogen index vs. oxygen index for samples from the Osprey D-36 well. Diagenetic pathways for the three main kerogen types are shown.

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Georgia Basin: Regional setting and adjacent Coast Mountains geology, British Columbia[1]

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Monger, J.W.H., Regional setting and adjacent Coast Mountains geology, British Columbia; *in* *Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 95-107, 1990.*

Abstract

The Upper Cretaceous to Neogene Georgia Basin is underlain by three different basements: Wrangellia terrane on the west, Coast Mountains on the east, and Cascade Mountains on the southeast. Basement structures, and seismic reflection data from Vancouver Island, suggest that the crust comprises a stack of thrust slices which formed in response to underthrusting of Pacific Ocean crust beneath western North America. Within the thrust stack, Wrangellia and western and central Coast Mountains were less deformed than structurally overlying eastern Coast Mountains and correlative parts of Cascade Mountains, and structurally underlying rocks on Vancouver Island and correlative westernmost Cascades. Georgia Basin formed largely upon this less deformed part of the evolving thrust stack, at a time when eastern parts of the stack were being disrupted by strike-slip faults. Basin rocks are preserved by Neogene and Holocene depression of the region between Vancouver Island and Coast Mountains.

Résumé

Le sous-sol du bassin de Géorgie, qui date du Crétacé supérieur au Néogène, est constitué de trois différents socles: terrane de Wrangellia à l'ouest, chaîne Côtière à l'est et chaîne des Cascades au sud-est. Les structures du socle et les données de la sismique réflexion de l'île Vancouver indiquent que la croûte est constituée d'un empilage de copeaux de charriage qui formés à la suite du sous-charriage de la croûte de l'océan Pacifique sous la partie occidentale de l'Amérique du Nord. À l'intérieur de l'empilage de copeaux de charriage, le terrane Wrangellia et les parties occidentale et centrale de la chaîne Côtière étaient moins déformés que la partie orientale de la chaîne Côtière et que les parties corrélatives de la chaîne des Cascades structuralement sus-jacentes ainsi que des roches de l'île Vancouver et des Cascades corrélatives les plus occidentales structuralement sus-jacentes. Le bassin de Géorgie s'est formé largement sur cette partie moins déformée de l'empilage évolutif des copeaux de charriage, à un moment où les parties orientales de l'empilage étaient dérangées par des failles à rejet horizontal. Les roches du bassin sont préservées par une dépression du Néogène et du Récent de la région située entre l'île Vancouver et la chaîne Côtière.

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[1] Contribution to Frontier Geoscience Program

INTRODUCTION

The primary purpose of Georgia Basin Project, a new component of the Frontier Geoscience Program (FGP), is to investigate hydrocarbon potential of Upper Cretaceous to Neogene sedimentary rocks in southwestern British Columbia that collectively constitute Georgia Basin. Basinal rocks are largely concealed beneath the waters of Georgia Strait and Pleistocene glaciomarine and Holocene (Recent) fluviodeltaic sediments of Fraser Lowland, and only exposed around the peripheries of these features. Accessible information on the basin was synthesized and evaluated recently by Gordy (1988) in an unpublished report for the British Columbia Ministry of Energy, Mines and Petroleum Resources.

Georgia Basin Project will provide new information within four general categories: (1) controls of basin formation and deep basin geometry; (2) internal geology and evolution of the basin; (3) processes governing generation, accumulation, and preservation of hydrocarbons; and (4) hazards and constraints to development. Preliminary results of research on Georgia Basin funded wholly or partly by FGP, with categories in brackets, are in reports in Current Research, Parts E and F by Bustin (2, 3), Clague (4), Luternauer (4), Monger (1) and Rouse (2). Related regional papers in Current Research, Part E are by Friedman, Journeay, Lynch, Riddell and Tyson.

This report outlines the regional structural setting of Georgia Basin, and also presents preliminary results of 1989 field work in the Coast Mountains, which structurally are the most poorly known part of the periphery of Georgia Basin.

GEORGIA BASIN: REGIONAL CONSIDERATIONS

Superimposed basins?

Georgia Basin comprises Upper Cretaceous (Santonian to Maastrichtian) marine and nonmarine clastic rocks of the Nanaimo Group; nonmarine Eocene and locally older clastic rocks of the Burrard, Chuckanut, and Kitsilano formations; and nonmarine Oligocene through Miocene clastics of the Huntingdon Formation. Cretaceous rocks outcrop mainly on the west side of Georgia Strait and Tertiary rocks on the east. Interrelated questions concern relationships of various rock units within the basin to one another, original extent and configuration of the basinal rock units, and their tectonic settings during deposition.

For older parts of the basin, Pacht (1984) and Johnson (1985) concluded that 2-4 km of Upper Cretaceous strata and (locally) over 6 km of lower Tertiary strata were deposited within pull-apart basins formed during oblique convergence between Kula(?) and North American plates. Ward and Stanley (1982) and England (1989) proposed that Upper Cretaceous rocks were deposited in a fore-arc trough, and Eisbacher (1985) in a fore-arc basin dominated by strike-slip faults. These rocks underwent early Tertiary compression, which formed northwesterly trending folds, and reverse and thrust faults (Miller and Misch, 1963; Johnson, 1985; England, 1989), prior to deposition of Huntingdon strata, which are dated by G.E. Rouse (personal communication) as Oligocene through Miocene. The Huntingdon is not strongly folded but is tilted to the southwest and locally cut by northeast-trending faults.

Muller and Jeletzky (1970) noted that Upper Cretaceous Nanaimo Group strata are preserved in a post-Cretaceous structural depression, one of a series of Neogene and Holocene linear depressions that extend from southernmost Alaska to southern Oregon, and lie about 150 km inboard of and parallel with the North American Plate margin. Proposed origins for the depression containing Georgia Strait are eastward tilting of Vancouver Island due to underthrusting of Juan de Fuca Plate (as in the lithospheric flexure model of Queen Charlotte Islands uplift/Hecate Strait depression proposed by Yorath and Hyndman, 1983); phase changes increasing density of the down-going Juan de Fuca Plate directly beneath Georgia Strait (Rogers, 1983); and rapid late Neogene differential uplift of the Coast Mountains due to warming and thermal expansion of lithosphere under the Coast Mountains but not beneath Georgia Basin (Parrish, 1983).

Basin basements

Georgia Basin lies on three basements: Wrangellian terrane on Vancouver Island to the west; Cascade Mountains to the south and southeast; and Coast Mountains to the east (Fig. 1). Basin evolution is controlled by events more clearly recorded in the basements than in the basin itself, because of better exposure and more varied geology in the surrounding regions.

The fundamental structure of the region is hypothesized to be a stack of crustal thickness of west-vergent thrust faults (Monger, 1989a; Monger et al., in press) that formed from latest Jurassic to Holocene time, in response to underthrusting of about 12 000 km of Pacific Ocean crust beneath the western North American Plate (Engebretson et al., 1988). Eastern parts of the thrust stack are disrupted by dextral strike-slip faults. This general interpretation of crustal structure is based on seismic reflection profiles on Vancouver Island, and the structural geology of Cascade and Coast mountains and Vancouver Island.

Wrangellia

The stratigraphy of Wrangellia on Vancouver Island comprises mainly unmetamorphosed and low-grade metamorphic sedimentary and volcanic units that range in age from Paleozoic through Jurassic, and granitic intrusions comagmatic with some of the volcanics (Muller, 1977). The structurally lowest part of Wrangellia, exposed on western Vancouver Island, is an igneous and metamorphic complex that probably is the root of the Jurassic magmatic arc. LITHOPROBE seismic reflection data indicate that Wrangellia is the 10-20 km thick uppermost plate of a 40 km thick stack of downward-younging thrust plates (Yorath et al., 1985; Clowes et al., 1987). Beneath Wrangellia, from top to base, are mainly Jura-Cretaceous clastic rocks (including Leech River schist); Eocene basalts (part of the Olympic Mountains province); imbricated sediments and volcanics (equivalent to the submerged Neogene to Holocene accretionary complex southwest of Vancouver Island); and the subducting Juan de Fuca oceanic plate. Although the uppermost, Wrangellian, thrust plate is largely continuous at the surface, it is internally imbricated on northeast-dipping faults, some of which are thrusts. One of these thrusts, the Beaufort Range Fault, juxtaposes Paleozoic and lower Mesozoic strata against Upper Cretaceous Nanaimo Group, which elsewhere lies stratigraphically on Wrangellia. Thus, some thrust faulting is late Late Cretaceous or younger. England (1989) mapped the structure of much of the Nanaimo Group as a fold and thrust belt.

Cascade Mountains

Cascade Mountains comprise (1) the western low grade metamorphic Northwest Cascades System (NWCS) which extends into the San Juan Islands on the west, (2) the axial Cascade Metamorphic Core (CMC), containing high-grade metamorphic rocks and granitic rocks, and (3) the eastern belt of low grade metamorphic rocks, composed of Hozameen and Methow terranes (HMT). Crustal structure of the Cascades was interpreted by Cowan and Potter (1986) as stacked early Late Cretaceous west-vergent thrust sheets. The stack was disrupted by Late Cretaceous-early Tertiary (70-50 Ma?), north-northwest trending dextral transcurrent faults (Monger, 1986; Tabor et al., 1989), although Brown (1987) felt that such faults played *the* major role in producing the regional structural pattern. The entire system was cut, probably in Late Eocene time, by the north-south trending, dextral strike-slip, Fraser-Straight Creek Fault, with a "best fit" of offset elements of about 100 km (Kleinspehn, 1985; Price et al., 1985), and by mid-Tertiary, Oligocene-Miocene northeast trending faults (Journeay and Csontos, 1989; Monger, in press).

Parts of Georgia Basin overlie pre-Late Cretaceous rocks of NWCS that comprise a variety of intensely folded and faulted volcanic and sedimentary strata, and at least four different but partly coeval terranes ranging in age from probable Precambrian-early Paleozoic, and definitely mid-Paleozoic through Cretaceous (Monger, 1985, 1986; Brandon et al., 1988; Tabor et al., 1989). Granitic rocks are rare. The distinctive high pressure and low temperature metamorphism of NWCS includes Late Jurassic-Early Cretaceous blueschist and early Late Cretaceous lawsonite-albite facies rocks. Dominant structures are early Late Cretaceous west-vergent, low- to high-angle thrust faults (Misch, 1966; Cowan and Potter, 1986; Brandon et al., 1988). Clastic and volcanic rocks, forming the "western and eastern melange belts" on the west side of NWCS in Washington (Frizzell et al., 1987; Tabor et al., 1989), are in part lithologically and structurally similar to the Leech River schist, which lies structurally below Wrangellia on southern Vancouver Island (Fig. 1).

East of NWCS, CMC contains mainly high-grade Barrovian and Buchan facies series metamorphic rocks, whose protoliths may be largely equivalents of rocks in NWCS (Monger, 1989b), as well as granitic rocks. CMC underwent protracted Late Cretaceous to Eocene metamorphism, deformation, and plutonism. Farther east, HMT includes upper Paleozoic to Cretaceous sedimentary and volcanic rocks of low metamorphic grade with a history of thrust faulting, sinistral (late Early Cretaceous) and dextral (late Late Cretaceous-early Tertiary) strike-slip faulting, and Tertiary normal faulting (Tabor et al., 1989).

Coast Mountains

By comparison with the Cascades and Wrangellia, structure of the Coast Mountains is relatively poorly known, largely because of the abundance of poorly dated granitic rock. Rock units within southernmost Coast Mountains are defined mainly by reconnaissance mapping (Roddick, 1965; Roddick and Woodsworth, 1979; Monger, in press), although several theses cover small areas in detail. Systematic U-Pb isotopic dating (being done by R.M. Friedman, University of British Columbia as part of LITHOPROBE), and regional structural studies should remedy the situation.

The eastern one-third of the southern Coast Mountains (east of Harrison Lake) differs geologically from the remainder, and is the northward continuation of Cascade geology (Crickmay, 1930; Misch, 1966; Monger, 1986). Structures and rock units can be traced across upper Fraser Lowland (east of Chilliwack) from Cascade Mountains into eastern Coast Mountains. The amount of granitic rock in eastern Coast Mountains is only marginally greater than that in CMC to the south.

By contrast, granitic rocks form about 80% of western and central southern Coast Mountains (Fig. 2). South of Fraser Lowland, NWCS contains little granitic rock. Western and central Coast Mountains rocks are represented in NWCS only by Jura-Cretaceous volcanics and sediments exposed in the Mount Baker structural window (Fig. 1; Misch, 1966).

As recognized by Crickmay (1930), the predominantly north-northwest trending Cascade structures of NWCS in Washington State bifurcate near 49°N (Fig. 1). On the east, they trend northeasterly to wrap around the east side of the central Coast Belt and extend north-northwesterly up the east side of Harrison Lake, where they are thrust over rocks to the west (Journeay and Csontos, 1989). On the west, they probably extend northwesterly from the western and eastern melange belts in Washington across Juan de Fuca Strait to link up with the Leech River schist on southern Vancouver Island, which is overthrust by Wrangellia on the San Juan(?)-Survey Mountain faults (Clowes et al., 1987). It is hard to avoid the conclusion reached by Crickmay (1930) that rocks of western and central Coast Mountains (and Wrangellia herein) form a *relatively* rigid block sandwiched between far more deformed rocks to the east and southwest. This block is not present to the south. Most of Georgia Basin lies upon this relatively rigid foundation.

The southeastern limit of Coast Mountains geology appears to lie in Fraser Lowland between Sumas and Vedder mountains and is delineated by the Vedder Fault (Fig. 1). This fault, however, is probably mid-Tertiary in age and one of the family of faults that east of Georgia Basin probably controls emplacement of mid-Tertiary granitic intrusions, and locally offsets rock units as young as 23 Ma (Journeay and Csontos, 1989; Monger, in press). The actual (exposed) boundary of Coast Mountains geology is the thrust fault surrounding the Mount Baker window farther south.

East of Harrison Lake, there is enormous structural relief. The metamorphic grade increases from subgreenschist facies near the lake to high amphibolite facies rocks (Bartholemew, 1977) 15 km to the east. Different lithostructural packages are stacked in west-vergent thrust sheets that feature down-dip northeast plunging mineral lineations and stretched clasts. These structures are cut by the north-northwest trending dextral Harrison Fault, which features subhorizontal stretching lineations (Monger, 1986; Journeay and Csontos, 1989).

CENTRAL, WESTERN COAST MOUNTAINS GEOLOGY, VANCOUVER MAP AREA

West of Harrison Lake, the Coast Mountains have much less structural relief than to the east. Correlative, Lower Cretaceous stratified rocks extend across almost the entire region (Fig. 2), and metamorphic grade is fairly uniform and rarely higher than high greenschist facies. The strongest deformation appears to be concentrated in relatively narrow, north-northwest trending shear zones, in a regional structural style which appears to be similar to that proposed by Yorath et al. (1985) for Wrangellia on Vancouver Island.

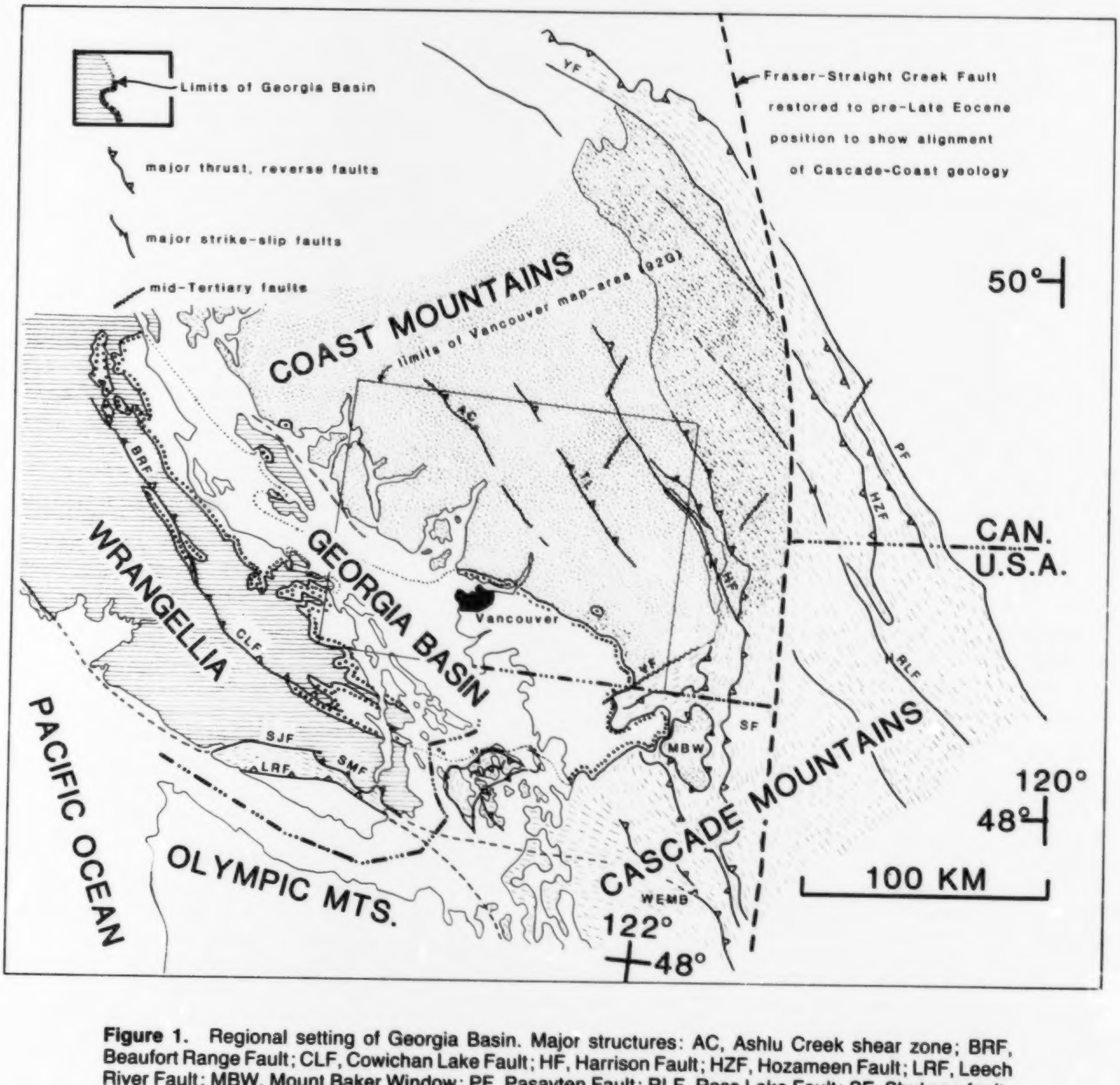
Limits of Georgia Basin
major thrust, reverse faults
major strike-slip faults
mid-Tertiary faults
Fraser-Straight Creek Fault
restored to pre-Late Eocene
position to show alignment
of Cascade-Coast geology
YF
COAST MOUNTAINS
limits of Vancouver map-area (92G)
50°
AC
AC
TL
PF
HZF
CAN.
U.S.A.
HF
BRF
WRANGELLIA
GEORGIA BASIN
Vancouver
CLF
VF
RLF
SF
MBW
SJF
SMF
LRF
CASCADE MOUNTAINS
120°
48°
PACIFIC OCEAN
OLYMPIC MTS.
WEMB
100 KM
122°
48°

Figure 1. Regional setting of Georgia Basin. Major structures: AC, Ashlu Creek shear zone; BRF, Beaufort Range Fault; CLF, Cowichan Lake Fault; HF, Harrison Fault; HZF, Hozameen Fault; LRF, Leech River Fault; MBW, Mount Baker Window; PF, Pasayten Fault; RLF, Ross Lake Fault; SF, Shuksan fault; SJF, San Juan Fault; SMF, Survey Mountain Fault; TL, Thomas Lake shear zone; VF, Vedder Fault; WEMB, Western and Eastern Melange Belt; YF, Yalakom Fault.

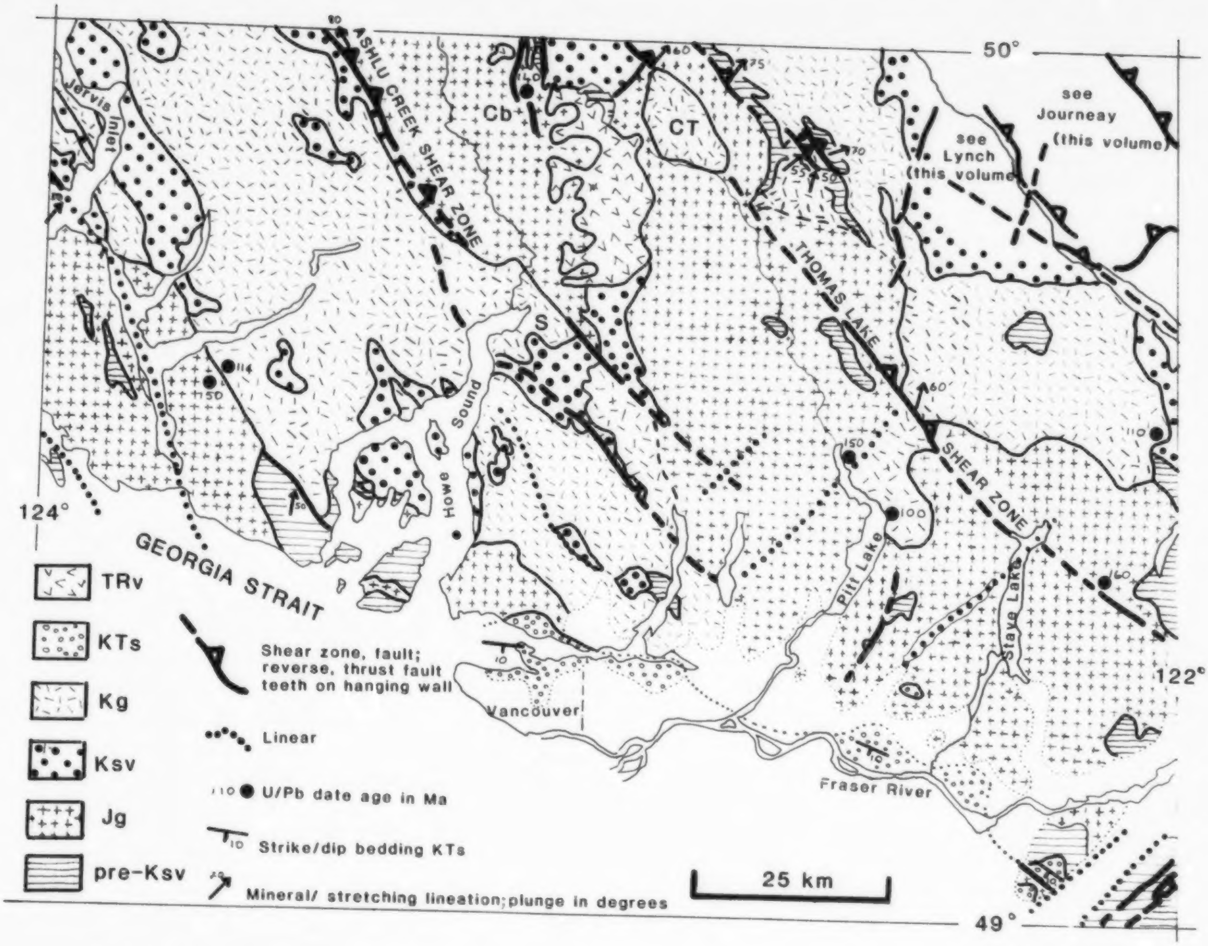
50°
see Journeay (this volume)
see Lynch (this volume)
Jervis Inlet
ASHLU CREEK SHEAR ZONE
Cb
CT
THOMAS LAKE
SHEAR ZONE
S
Howe Sound
114
150
150
100
110
160
60
75
70
55
50
10
124°
122°
49°
GEORGIA STRAIT
Vancouver
Pitt Lake
Stave Lake
Fraser River
TRv
KTs
Kg
Ksv
Jg
pre-Ksv
Shear zone, fault; reverse, thrust fault teeth on hanging wall
Linear
U/Pb date age in Ma
Strike/dip bedding KTs
Mineral/ stretching lineation;plunge in degrees
25 km

Figure 2. Simplified geology, Vancouver map area (92G), based on 1989 field work, and Roddick (1965), Roddick and Woodsworth (1979). Granitic rocks (known, possible ages) are Jg, Middle(?) and Late Jurassic; Kg, Early and mid-Cretaceous; Cb, Cloudburst pluton; CT, Castle Towers pluton; S, Squamish pluton. Preliminary U-Pb dates provided by R.M. Friedman.

Rock units

Georgia Basin rocks of mainly early Tertiary but locally Cretaceous age lie on a pre-latest Cretaceous erosion surface along the southernmost Coast Mountains. The fossiliferous Middle Triassic through Lower Cretaceous section on the west side of Harrison Lake (Arthur, 1986) is probably the best preserved section within the entire Coast Mountains, but 20 km farther west its stratigraphy is obscured by abundant Jurassic and Cretaceous granitic rocks. The youngest part of the Harrison Lake section (Peninsula, Brokenback Hill formations) consists of Lower Cretaceous sedimentary and volcanic rock with locally prominent basal granitic clast conglomerate. These rocks, together with partly or wholly coeval units (Cheakamus and Helm formations, Fire Lake and Gambier groups) are the only units that can be correlated with confidence across Vancouver map area, and provide a useful marker horizon for estimating displacements on structures. The Jurassic Harrison Lake Formation, 3000 m thick near Harrison Lake and featuring distinctive keratophyre and quartz keratophyre flows, occurs near Pitt River 30 km west of Harrison Lake but cannot be identified with confidence any farther west. The pre-Late Jurassic Bowen Island Group, exposed in Howe Sound area and to the west, may be correlative as it also contains felsic volcanic rocks. Bowen Island Group could equally well be equivalent to similar volcanic units on Vancouver Island, such as the Jurassic Bonanza or Paleozoic Sicker groups, particularly as it is associated with basaltic volcanics identified as Karmutsen Formation by Roddick and Woodsworth (1979). Fossiliferous Upper Triassic hornfelsed argillite on Fissile Peak, east of the village of Whistler and 2 km north of the northern limit of Vancouver map area, is the only pre-Cretaceous fossiliferous unit known. Rocks mapped as Cretaceous, such as part of the Gambier Group near Whistler (Woodsworth, 1977) and part of the Empetrum Formation (Mathews, 1958), more closely resemble facies of the Upper Triassic Cadwallader Group as they contain granitic and diorite clast conglomerate associated with carbonate.

Although far more isotopic dating is needed, indications are that ages of most granitic rocks in Vancouver map area are mainly either Middle-Late Jurassic (175(?)-140 Ma) or Early to mid-Cretaceous (114-100 Ma) (Roddick and Woodsworth, 1979; Friedman, 1989; R. Friedman and R.L. Armstrong, personal communication). Jurassic granitic rocks are abundant between Thomas Lake and Ashlu Creek shear zones, and in Sechelt Peninsula in the western part of Vancouver map area (Fig. 2). Cretaceous granitic rocks are relatively abundant east of Thomas Lake shear zone, and predominate between Ashlu Creek shear zone and Sechelt Peninsula.

Metamorphic rocks (mainly mapped as Twin Island Group by Roddick, 1965) are of greenschist or in places possibly lowest amphibolite grade facies. Fine grained quartz-biotite schist and amphibolite typically form screens between granitic bodies. Granite-clast conglomerate and volcanic breccia textures are locally preserved within the schist. In places, as for example in the Garibaldi area, Mamquam River valley east of Squamish, and Pitt River valley, regional retrograde metamorphism featuring extensive development of chlorite and/or sericite in granitic rocks is associated with late, brittle deformation.

Structures

Cretaceous structures

The most prominent structures in the Coast Belt in the Vancouver area are north-northwest trending zones of high strain containing schistose rocks. These are located (1) near Harrison Lake Lillooet River valley, (2) south from Cheakamus River valley just south of Whistler to near Stave Lake (Thomas Lake shear zone), (3) south from Ashlu Creek to Stawamus-Indian River valleys (Ashlu Creek shear zone), and (4) (possibly) along the west side of Sechelt Peninsula (Fig. 2). The shear zones extend for many tens of kilometres along strike and range in width from a few hundred metres up to 2 km (Fig. 2). Smaller shear zones that are traceable for only a few kilometres along strike occur near Snowcap Lake and Snowbowl Glacier in north-central Vancouver map area, and in the Jervis Inlet, Sechelt Peninsula, and Britannia areas in the southwest. Between the shear zones, stratified Cretaceous rocks are folded and granitic rocks contain flow fabrics, but the rocks typically are less deformed. As Lower Cretaceous strata occur in all panels between the shear zones, except for the westernmost, displacements on the shear zones may not be very large.

Within the shear zones, mylonitic and flattening fabrics dip 60-80° to the northeast, and generally feature down-dip stretching lineations and metamorphic mineral alignments. Asymmetric fabrics, locally present within Ashlu Creek and Thomas Lake shear zones and on Sechelt Peninsula, suggest that in these places the northeast side of the shear zone has moved up relative to the southwest. Subhorizontal stretching lineations, like those along the dextral strike-slip Harrison Fault, were not seen west of Harrison Lake.

Fabrics related to the shear zones occur in rocks as young as Lower Cretaceous, and Ashlu Creek and Thomas Lake shear zones appear to be cut by, respectively, Squamish Pluton (100 Ma; R.L. Armstrong, personal communication) and the (undated) Castle Towers Pluton. In style, orientation, and movement sense, fabrics on the shear zones resemble those on the late generation thrust faults to the east (Journeay and Csontos, 1989), but the latter are dated on the basis of relationships to intrusions as being early Late Cretaceous (91-87 Ma; J.M. Journeay, R. Friedman, personal communication). It should be noted that rocks predating the Cretaceous in the southwestern part of the map area have planar fabrics that almost certainly are older and unrelated to the shear zones.

Tertiary (?) structures

Northeast-trending faults, such as that extending southwest from Glacier Lake in the northeast of the area, cut schistose rocks with probable Cretaceous fabric. Other, northeast-trending linears (near Alouette Lake, Blanshard Peak, and between Pitt and Coquitlam lakes) possibly are developed along faults, and that along Alouette Lake appears to offset the Thomas Lake shear zone. The northeasterly orientation of these linears suggests that they are related to similarly orientated mid-Tertiary faults found to the east.

In the vicinity of Daisy Lake in Cheakamus River valley to the north, and in the Mamquam River valley, brittle shear zones intensely developed within Cloudburst quartz diorite, contiguous schists and locally Cretaceous conglomerate form a north-trending zone up to 6 km wide (Mathews, 1958). In places the rocks are completely brecciated, and chlorite and less commonly sericite are developed on shear surfaces. On the mesoscopic scale, blocks of rock (containing Cretaceous or older gneissose and mylonitic fabrics) are bounded by steeply dipping surfaces that in places present a sigmoidal pattern in plan view. Their orientation suggests that deformation took place within a dextral shear zone trending 0-10°E. Age of the deformation is unknown, other than it is post-Early Cretaceous.

CONCLUSIONS AND FUTURE WORK

Controls of Georgia Basin formation can most readily be understood by examining structures in basement rocks around its periphery, rather than restricting studies to the poorly exposed basin. The structures suggest that most of Georgia Basin lies upon an upper crustal plate comprising central and western Coast Mountains and Wrangellia, that is imbricated on northeast dipping reverse faults, none of which have large displacements. Timing of reverse faulting within the Coast Mountains is mid-Cretaceous, but that on Vancouver Island appears to be younger since it involves the Upper Cretaceous Nanaimo Group. Although Georgia Basin deposition took place at the same time as north-northwest-trending dextral strike-slip faulting to the east, no evidence was seen for this type of movement within the Coast Mountains, west of Harrison Lake. Future structural studies will define ages of these structures in the Coast Mountains, and identify them within Georgia Basin rocks, using both geology and geophysics within the basin.

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Stratigraphy, sedimentology, and petroleum source rock potential of the Georgia Basin, southwest British Columbia and northwest Washington State[1]

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Bustin, R.M., Stratigraphy, sedimentology, and petroleum source rock potential of the Georgia Basin, southwest British Columbia and northwest Washington State; in Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 103-108, 1990.

Abstract

Upper Cretaceous and Tertiary strata along the eastern margin of Georgia Basin include nonmarine and transitional marine clastic rocks and coal. The succession thickens from the erosional edge at the northern margin, to 670 m at Abbotsford, to >4400 m at Point Roberts. Surface and subsurface stratigraphy cannot be readily correlated by lithology. Level of organic maturation of strata along the basins margin is highly variable (0.3->2 % mean random vitrinite reflectance). Subsurface strata are immature to mature with respect to oil generation. Maturation inexplicably does not appear to increase with depth of burial. The strata have moderate to poor petroleum source rock characteristics. They contain mainly gas prone Types II and III organic matter with hydrogen indices generally <300 mg HC/g TOC. The highly variable total organic carbon contents correlate with the presence or absence of discrete carbonaceous partings and coal.

Résumé

Les couches du Crétacé supérieur et du Tertiaire qui longent la marge orientale du bassin de Géorgie comprennent des roches détritiques non marines et marines de transition ainsi que du charbon. La série va s'épaississant : elle commence par un rebord d'érosion sur sa marge septentrionale, atteint 670 m à Abbotsford et dépasse 4400 m à Point Roberts. Les couches sont généralement à grain plus fin à mesure qu'on s'éloigne des marges du bassin. La lithologie ne suffit pas à établir la corrélation de la stratigraphie de surface et de subsurface. Le niveau de maturation organique des couches le long de la marge du bassin est extrêmement variable (réflectance aléatoire moyenne de la vitrinite de 0,3 à plus de 2 %). Les couches souterraines sont immatures à matures quant à la production de pétrole. La maturation ne semble pas augmenter avec la profondeur de l'enfouissement. Les couches ont des caractéristiques de roche mère pétrolifère modérées à médiocres. Elles renferment surtout de la matière organique à potentiel gazifère de type II et de type III, avec des indices d'hydrogène généralement 300 mg HC/g de carbone organique total. Les teneurs en carbone organique total fortement variables correspondent à des divisions charbonneuses discrètes et à du charbon.

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INTRODUCTION

Southwestern mainland British Columbia and adjacent parts of northwestern Washington include a thick succession of Upper Cretaceous and Tertiary strata which were deposited in a structural reentrant in the Coast and Cascade mountains. These strata form the eastern margin of Georgia Basin, an Upper Cretaceous and Tertiary structural and sedimentological basin(s) that at various times encompassed Georgia Depression, Comox, Nanaimo, and Suquash basins of eastern Vancouver Island, the Gulf Islands and the Whatcom Basin (Bellingham Basin) of northwest Washington (Miller and Misch, 1963; Johnson, 1984; Bickford and Kenyon, 1988; England, 1989). Georgia Basin includes a succession at least 6 km thick of marine, fluvial-deltaic and alluvial sediments. The basin embraces strata assigned to the Nanaimo Group on Vancouver Island and the Gulf Islands; the Burrard, Huntingdon and Kitsilano formations of southwestern mainland British Columbia; the Chuckanut Formation of northwestern Washington; and an unnamed subsurface succession more than 4.5 km thick in Fraser Lowland.

This study documents the lateral and stratigraphic variations in degree of organic maturation and petroleum source rock potential in Georgia Basin and interprets the maturation history in the context of basin evolution. During the initial phase of the study summarized here, well cuttings and core were sampled from exploratory drillholes in the Fraser Lowland, and preliminary lithostratigraphic studies of subsurface logs and surface sections were begun (Fig. 1). The stratigraphy of the study area is reviewed in this report and interpreted, and preliminary source rock and maturation data are presented.

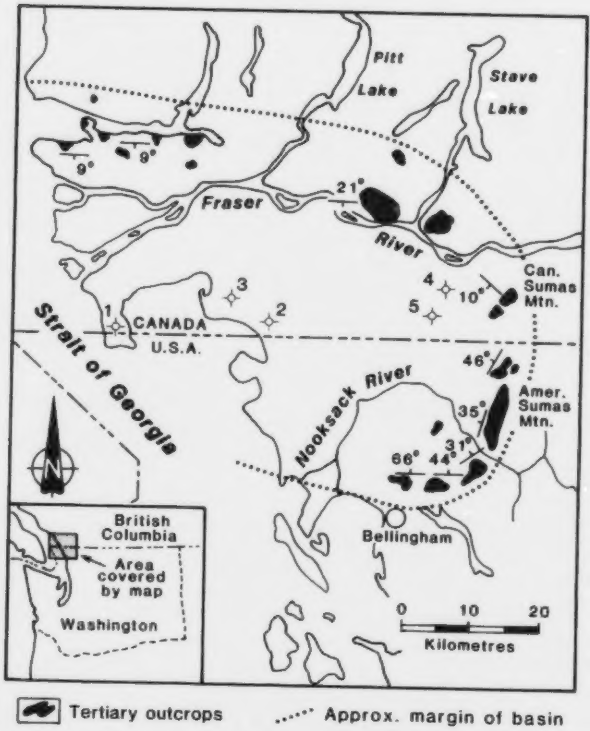

Figure 1. Index map, with generalized distribution of Tertiary strata in southeastern Georgia Basin (modified in part from Miller and Misch, 1963). Exploratory drillholes discussed in text are: 1-Richfield Point Roberts; 2-Delta Kuhn, 3-Richfield Sunnyside, 4-Richfield Abbotsford, 5-Hercon Evans.

PRE-QUATERNARY STRATIGRAPHY OF THE FRASER LOWLAND

Fraser Lowland is the surface expression of a major structural reentrant in the Coast and Cascade mountains that has existed at least periodically since Late Cretaceous time. For the most part, the Fraser Lowland is mantled by thick (locally in excess of 300 m) and locally dissected Pleistocene sediments, together with Holocene (Recent) alluvium of the Fraser River (Mathews et al., 1970).

Tertiary strata underlie and outcrop locally along the margins of Fraser Lowland (Fig. 1). Most marginal strata dip towards the structural centre of the reentrant. Clastic rocks outcropping along the northern flank of the basin have been assigned to the Burrard, Huntingdon or Kitsilano formations (Rouse et al., 1975; Fig. 2). The Burrard Formation is a sequence of conglomerate, feldspathic sandstone, and shale up to 700 m thick that underlies much of the City of Vancouver and outcrops as far east as Burnaby Mountain (Johnston, 1923). It nonconformably overlies plutons of the Coast Mountains and dips 10-15° south. The Burrard Formation has been thought to include both Eocene and Upper Cretaceous strata (Rouse et al., 1975; Fig. 2). Upper Cretaceous strata, referred to as the Lions Gate Member (Rouse et al., 1975) comprise interbedded conglomerate, sandstone and mudstone and rest nonconformably on intrusive rocks. Rouse et al. (1975) suggested that the Lions Gate Member is "essentially correlative" with the Extension-Protection Formation of the Nanaimo Group. The contact between the Lions Gate Member and overlying younger strata (unnamed) of the Burrard Formation is disconformable. The Kitsilano Formation is up to 760 m thick and is composed of a sequence of conglomerate, sandstone, and shale with thin lignite. The formation is presumed to be of mid-Eocene and possibly Early Oligocene age and disconformably overlies the Burrard Formation (Johnston, 1923; Hopkins, 1966). The formation outcrops at Kitsilano Beach, the southern shore of Burrard Inlet and east of Burnaby Mountain.

The eastern margin of the Fraser Lowland reentrant is exposed at Canadian Sumas Mountain and American Sumas Mountain. On Canadian Sumas Mountain, a sequence of gently southwest-dipping (10-15°) clastic rocks up to 365 m thick are exposed. These are assigned to the Huntingdon Formation, which has been considered Middle-Late Eocene in age and nonconformably overlies intrusive rocks of the Coast Mountains (Roddick, 1965). The strata on Canadian Sumas Mountain comprises an overall coarsening-upward sequence of conglomerate, shale, sandstone, and thin seams of high volatile bituminous coal (Horton, 1978). On American Sumas Mountain the Huntingdon Formation is 460 m thick (Miller and Misch, 1963). The Huntingdon Formation is correlative in part with the Burrard and Kitsilano formations.

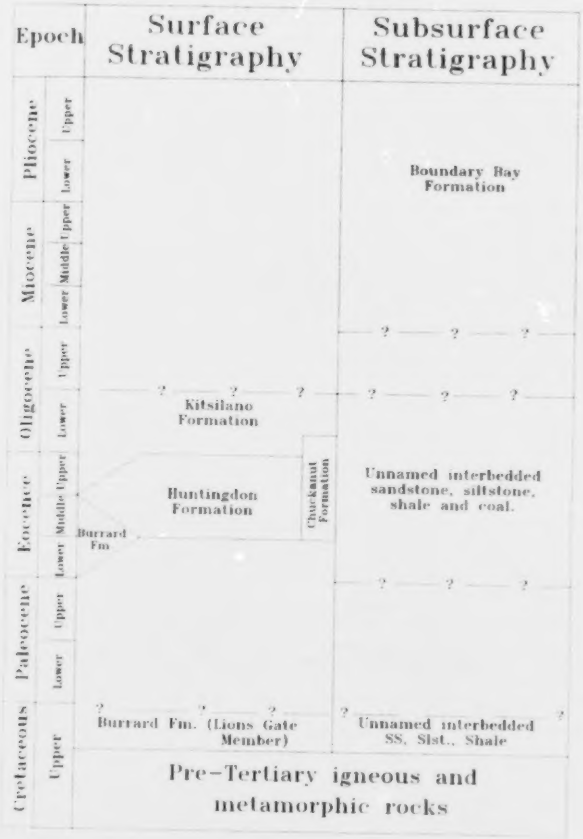

Figure 2. Stratigraphic nomenclature applied to surface and subsurface strata in the study area. The subsurface stratigraphy cannot be correlated with surface stratigraphic units based on lithology alone. Modified from Johnston (1923), Hopkins (1966) and Rouse et al. (1975).

Along the southeastern and southern margins of the Georgia Basin a thick (about 6000 m) succession of fine and coarse grained clastic rocks including coal of the Eocene Chuckanut Formation outcrop. The Chuckanut occupies a wide belt of outcrop from Sucia Island to Slide Mountain and overlies a "diverse pre-Tertiary basement" (Johnson, 1984).

Subsurface geology

Subsurface geology of the Fraser Lowland is known from wire line logs, drill cuttings, and minor core obtained from exploratory drillholes, and descriptions of early exploration drillholes that were not logged by geophysical methods (Johnston, 1923; Hopkins, 1966). Stratigraphic correlation between surface exposures and subsurface strata is not possible based solely on lithology. With few exceptions, strata exposed along the margin of the basin are coarser grained than their subsurface equivalents, reflecting deposition closer to highland source terrains than strata in the subsurface. Correlation of the subsurface stratigraphy based on available wire line logs is difficult because of rhythmic interbedding of the strata and general absence of horizons with distinct log signature.

From east to west across the Fraser Lowland there is a marked thickening in the stratigraphic succession. At Abbotsford (Richfield Abbotsford) about 670 m of strata overlie granitic basement. About 6.5 km southwest (Hercon Evans; Fig. 1) 1850 m of strata overlie basement. Drillholes farther to the west did not encounter basement and, in the Point Roberts area (Richfield Pure Point Roberts), at least 4400 m of strata overlie basement. The strata are mainly interbedded fine to coarse grained sandstones, green, red and black shales, and siltstones, and rare thin seams of coal and conglomerate beds and lenses up to 2.5 m thick. The sandstones average about 4 m thick whereas the finer grained shale and siltstone intervals are up to 60 m thick. The lithologies are evenly distributed throughout the succession. Based on the log signature, the stratigraphic succession appears to be mainly nonmarine or transitional marine. In the Richfield Point Roberts and Richfield Sunnyside wells, this interpretation is supported by the absence of marine microfossils (Hopkins, 1966). Most sandstones fine upwards or show little variation in grain size (as interpreted from the wire line logs) and are probably channel and/or crevasse splay deposits. Less common are sandstones up to 10 m thick that display distinct coarsening upward trends, and are interpreted as beach and/or offshore bar deposits. Shales underlying or overlying the beach sands may be transitional marine in origin but most of the shale/siltstone intervals are probably nonmarine.

Age of strata in the subsurface is poorly known. Based on palynological studies, Hopkins (1966) tentatively suggested that in the Richfield Point Roberts drillhole, strata from 280-1600 m are Miocene, from 1600-3400 m are Middle and Late Eocene, and between 3400-4800 m, are Late Cretaceous. In the Richfield Sunnyside well, Hopkins (1966) interpreted the upper 1633 m to be Miocene and younger, from 1633-2980 m to be Middle and Late Eocene, and from 2980-3632 m to be Late Cretaceous. In the Boundary Bay No. 3 drillhole, the strata (referred to as the Boundary Bay Formation by Johnston, 1923) is thought to be Pliocene or possibly Miocene in age (Johnston, 1923; Hopkins, 1966). These ages should be regarded as speculative.

TECTONIC AND SEDIMENTOLOGICAL HISTORY

The Late Cretaceous and Tertiary history of Fraser Lowland is poorly known. The stratigraphy, as summarized and analyzed above, is neither rigorous nor well dated but does facilitate some general interpretations of the tectonic and sedimentological history of this part of the Georgia Basin. The Lions Gate Member of the Burrard Formation and Upper Cretaceous strata of the subsurface of the Fraser Lowland appear to be correlative with part of the Nanaimo Group of Vancouver Island and the Gulf Islands. To the west, on Vancouver Island, Nanaimo Group unconformably overlies upper Paleozoic and lower Mesozoic rocks of Wrangellia and along the north margin of the Fraser Lowland the Lions Gate Member nonconformably rests on intrusive rocks of the Coast Mountains. The Nanaimo Group, the Lions Gate Member and correlative strata in the subsurface had source areas on Vancouver Island, San Juan

Islands and Coast Mountains (Ward and Stanley, 1982; Johnson, 1984). It is likely that the Comox, Nanaimo, and Fraser Lowland sub-basins of Georgia Basin were contiguous during the Late Cretaceous. The basin(s) developed in a fore-arc position on Wrangellia exotic terrain mainly oceanward of the Cretaceous magmatic arc of the Coast Mountains. Southern and eastern margins of the basins are probably uplifted metamorphic and plutonic rocks of the Cascades.

Paleocene strata have not been documented from the Georgia Basin and it is probable that the Paleocene was a time of uplift and emergence.

During the Eocene a thick succession of nonmarine clastics of the Chuckanut Formation and correlative strata were deposited in northern Washington State. These strata probably accumulated in intermontane sub-basins formed in response to dextral slip along extensions of the Straight Creek Fault and a major dextral fault to the west (Johnson, 1984; also see Ewing, 1980). The main westerly dextral fault was thought by Johnson (1983) to be an extension of the Leech River Fault of Vancouver Island, to have been active until Late Eocene-Oligocene(?) time and to have culminated with emplacement of the Leech River Complex. Along the northeastern margin of the Georgia Basin coarse and fine grained clastics of the Burrard, Kitsilano, and Huntingdon Formations were deposited. Away from the margins of the basin finer grained clastics accumulated predominantly in fluvial and deltaic environments.

The Miocene-Pliocene history of the Georgia Basin is known only from the subsurface of the Fraser Lowland. Hopkins (1966) suggested that a thickness of the order of 1200 m of Miocene sediment may be present in the Boundary Bay #3, Richfield Sunnyside, and Point Roberts wells. Correlative Miocene-Pliocene strata are absent from the adjacent basin margin and were likely eroded during post-Miocene differential uplift of the margins, estimated at 1-2 km (Mathews, 1972). In the southern part of the basin the Chuckanut Formation was uplifted, folded, and faulted in post-Eocene time.

PETROLEUM SOURCE ROCK POTENTIAL AND ORGANIC MATURATION OF GEORGIA BASIN

To assess the petroleum source rock potential and level of organic maturation, well cuttings, core and outcrop samples are being studied by Rock-Eval pyrolysis, total organic carbon analysis, vitrinite reflectance, and gas chromatography. Preliminary results indicate that along the southern margin of the Fraser Lowland the level of organic maturation is extremely variable, ranging from about 0.3% $R_o$rand (mean random vitrinite reflectance) to over 2% $R_o$rand. The higher values reflect the proximity of the strata to intrusive rocks. Along the northern margin of the basin at Canadian Sumas Mountain, the Huntingdon Formation has been thermally affected by adjacent intrusives and vitrinite reflectance values range up to 0.70%. Preliminary vitrinite reflectance analyses of cuttings and core from the from the Delta Kuhn, Richfield Sunnyside, and Richfield Point Roberts holes have yielded ambiguous results. The vitrinite reflectance values of samples vary from about 0.40-0.60% and show no significant increase with depth of burial.

Vitrinite reflectance data from the Richfield Point Rober well (Fig. 3) show little or no increase in maturation wi depth, as would be expected by the generally greater the mal exposure of strata lower in the stratigraphic successic (Bustin et al., 1985). Even samples buried to relatively sha low depths (<700 m) have vitrinite reflectance value around 0.50% which, assuming reasonable geothermal gra dients and subsidence rates, suggests burial depths of th order of several kilometres, inconsistent with the subsidenc history of the strata as currently understood. The ambiguit of the available vitrinite data prevents any rigorous interpre tations. It can only be concluded that the strata are immatur to mature with respect to hydrocarbon generation.

Rock-Eval and total organic carbon (TOC) analyses ar currently in progress. Results obtained to date from th

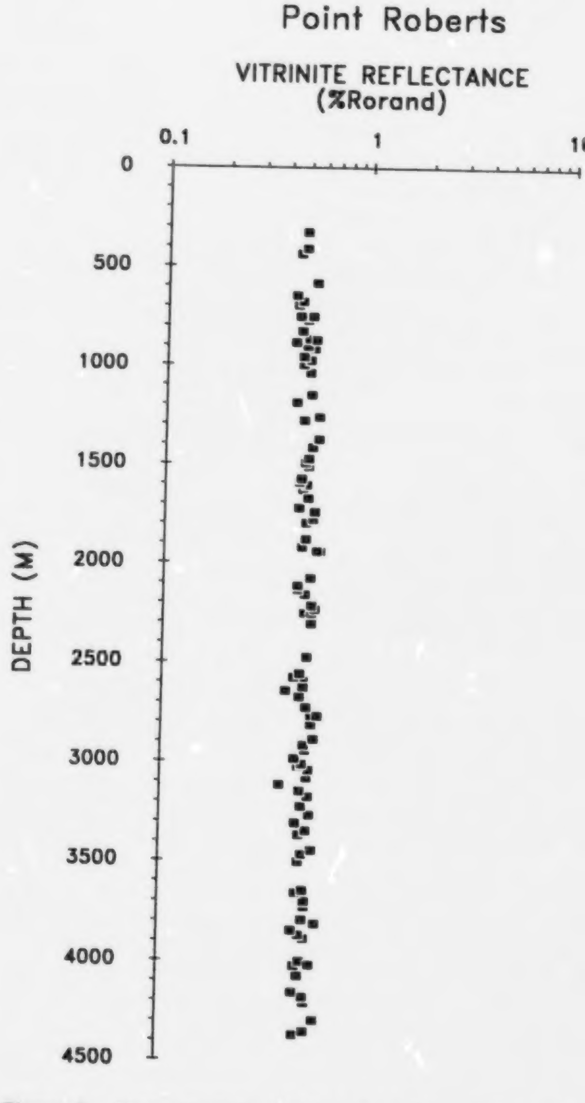

Figure 3. Mean random vitrinite reflectance verse depth for selected samples from the Richfield Point Roberts well. All samples are hand picked cuttings.

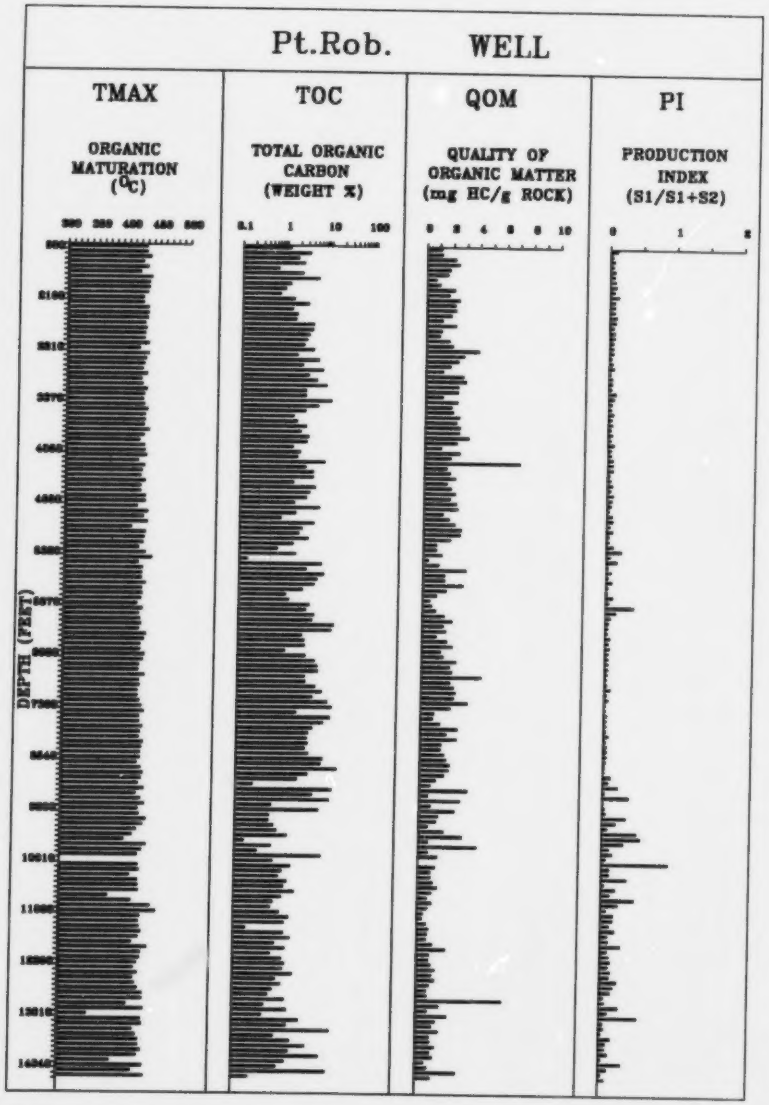

Figure 4. Summary of Rock-Eval data, Richfield Point Roberts well. The analyzed samples are all hand picked cuttings.

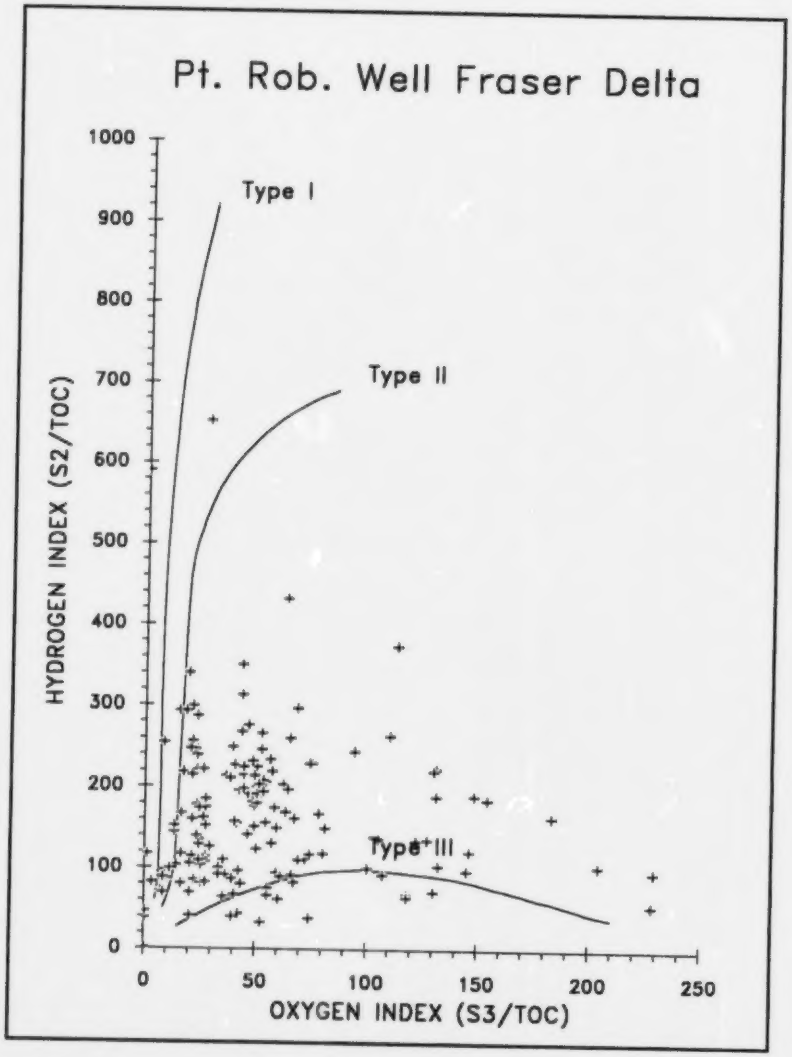

Figure 5. Hydrogen index vs. oxygen index for hand picked cutting samples from the Richfield Point Roberts well. Diagenetic pathways for the three main kerogen types are shown (see Tissot and Welte, 1984).

Richfield Point Roberts well are summarized in Figures 4 and 5. The analyzed samples vary widely in source rock quality. As generally classified (e.g., Tissot and Welte, 1984) the analyzed samples have poor to moderate petroleum source rock potential and comprise Type II (oil and gas prone) and Type III (gas prone) organic matter with hydrogen indices generally less than 300 mg HC/g TOC (Fig. 5). The TOC content is highly variable with depth, which mainly reflects the presence of discrete carbonaceous partings through out the succession. The quality of the organic matter (QOM) and production index (PI) are generally low but moderately rich source rock intervals occur throughout the succession (Fig. 4). Average Tmax increases from about 420°C to about 450°C from the top to the base of the well.

ACKNOWLEDGMENTS

I thank Dr. W.H. Mathews and Ms. M. Lamberson of The University of British Columbia, for their comments on an early version of this report.

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Palynology of Cretaceous and Tertiary strata of Georgia Basin, southwestern British Columbia[1]

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Rouse, G.E., Lesack, K.A., and White, J.M., Palynology of Cretaceous and Tertiary strata of Georgia Basin, southwestern British Columbia; in Current Research, Part F, Geological Survey of Canada Paper 90-1F, p. 109-113, 1990.

Abstract

Samples of Upper Cretaceous sediments from many of the Gulf Islands, from eastern Vancouver Island, and from the shore of Stanley Park in Vancouver have yielded reasonably good palynoassemblages, with mixed dinocysts, pollen and spores in many samples. Samples from the Burrard and Kitsilano formations have given reasonably good Eocene palynoassemblages. Of significance is the recognition of Paleocene assemblages in the lower part of the Chuckanut Formation from the southern part of the basin and in the uppermost beds of the Nanaimo Group.

Résumé

Des échantillons de sédiments du Crétacé supérieur provenant d'un grand nombre d'îles Gulf, de la partie orientale de l'île Vancouver et du littoral du parc Stanley de Vancouver ont fourni d'assez bons palynoensembles avec des dinokystes et des pollens/spores mélangés dans de nombreux échantillons. Des échantillons provenant des formations de Burrard et de Kitsilano ont donné d'assez bons palynoensembles de l'Éocène. Est particulièrement significative la reconnaissance d'ensembles du Paléocène dans la partie inférieure de la formation Chuckanut de la partie méridionale du bassin et dans les lits supérieurs du groupe de Nanaimo.

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INTRODUCTION

Palynology has been a powerful technique for determining ages and paleoenvironments of the largely nonmarine strata of Georgia Basin. The earliest palynological study of Georgia Basin was by Rouse (1957) on the Upper Cretaceous Nanaimo Group from the east coast of Vancouver Island. This was followed by discovery of correlative Upper Cretaceous beds on north and south shores of Burrard Inlet in Vancouver by Rouse (1962), Crickmay and Pocock (1963), and Rouse et al. (1971, 1975). The Middle Eocene component of Burrard Formation was described by Rouse (1962) and Rouse et al. (1971), and an important Miocene section was recognized by Hopkins (1968). Griggs (1971) described the palynology of the Chuckanut Formation of northwestern Washington, calling it all Paleocene. Paleocene, Eocene, and Oligocene palynoassemblages were determined by Reiswick (1982) from the Chuckanut-Huntingdon succession in northwestern Washington, which provides links to the Tertiary sequence in the Burrard Inlet region of southwestern British Columbia. Current understanding of the most probable ages of rocks of Georgia Basin is given in Figures 1 and 2.

The present work is intended to provide a complete palynological biostratigraphy for Georgia Basin, to aid in correlation of intra-basinal rock units, and to establish paleoenvironments. The first stage of the palynological program has entailed collecting and processing samples of Upper Cretaceous sediments from many of the Gulf Islands, including Lasqueti, Gabriola, Galiano, Saltspring, Mayne, and North Pender; from the mouth of Nanaimo River, and the upper part of the Brothers Creek Member along the north shore of Stanley Park in Vancouver. These have yielded reasonably good palynoassemblages, with mixed dinocysts and pollen and spores in many samples. Also included in this first stage was the sampling and processing of samples from the Burrard and Kitsilano formations along the Stanley Park foreshore, with reasonable recovery of Eocene palynoassemblages. Of significance is recognition of Paleocene assemblages in the lower part of the Chuckanut Formation from the Bellingham (southern) region of the basin, and in uppermost Nanaimo beds at the north end of Lasqueti Island.

Results to date are encouraging, indicating a good prognosis for extending the program to include the remaining Gulf Islands, and particularly the Richfield and Canadian Hunter wells in the Fraser Delta. This will give a picture of the overall palynostratigraphy through the Cretaceous and Tertiary intervals, and also provide evidence for the large tectonic anomaly between the Vancouver-Point Roberts section, which features mainly Tertiary rocks, and that of the largely Cretaceous Nanaimo succession immediately to the west. A major objective of this project is to describe palynoassemblages from the various units, and to make more precise dating and correlation of the stratigraphic units.

PRELIMINARY LISTS OF PALYNOMORPHS FROM SERIAL STRATIGRAPHIC UNITS

1. Comox Formation, east coast of Vancouver Island; **Santonian**.
   Spores:

   Gleicheniidites senonicus
   Cyathidites minor
   Deltoidospora rhytisma
   Microreticulatisporites irregularis
   Acanthotriletes typicus
   Perotriletes granulatus
   Stereisporites cingulatus subsp. *cingulatus*
   Cibotiumsporites concavus

   Pollen:

   Sparganiaceaepollenites polygonalis
   Proteacidites thalmanii
   Engelhardtia spackmaniana
   Triatriopollenites manifestus
   T. granifer
   Tricolpites laesus
   T. minutus

2. Extension-Protection Formation, east coast of Vancouver Island, and correlative beds on Orcas Island, Brothers Creek Member, north and south shore of Burrard Inlet, and Wolfson Creek east of Powell River. **Campanian**.
   Spores:

   Deltoidospora microforma
   Hymenophyllumsporites papillosus
   Appendicisporites cristata forma fenestrata
   Cicatricosisporites striosporites
   C. dorogensis
   C. striatus

   Pollen:

   Cycadopites follicularis
   Monosulcites sp. cf. *sabal*
   Liliacidites spp.
   Proteacidites thalmanii
   P. marginus
   P. bellus
   Cupaneidites reticularis
   C. major
   Tricolpites fusiformipollenites
   T. rhamoides
   Tricolporopollenites punctatus

With the exception of *Proteacidites thalmanii*, the species of palynomorphs from the Extension-Protection Formation and correlatives are distinct from those of the Comox, and hence will be valuable for dating and correlating other surface as well as subsurface sections.

3. Upper Lasqueti Islands beds and Lower Chuckanut Formation. **Paleocene**.
   Fungal spores:

   Multicellaesporites irregularis
   M. fusiformis
   M. "filamentis"

Callimothallus pertusus
Fractisporonites ordinatus
Staphlosporonites conoideus
Pluricellaesporites psilatus
P. "attenuatus"
Pesavis n. sp.

Pollen:

Carya viridifluminipites
Engelhardtia sp.
Paraalnipollenites alterniporus
Carpinipites spackmaniana
Cedrus perialata
Picea grandivescipites
Pinus haploxylon-type

4. Burrard Formation. **Lower to Middle Eocene**.
Fungal Spores:

Fusiformisporites crabbii
Punctodisporites A   *Magnosporites staplinii*
Granatisporites cotalis
Inapertisporites globulosus
I. elongatus
Multicellaesporites spp.

PLIOCENE-HOLOCENE		Glacial and non-glacial litho-units	
		Panorama Ridge	
		Sub-Fraser Delta deposits (ca. 625 m)	
MIOCENE		Boundary Bay Formation	
		"South Westminster" Formation	
		Richfield well sections	
OLIGOCENE		Kanaka Creek (Haney)	Huntingdon Formation
		Toad Lake Beds	
EOCENE	UPPER MIDDLE	Kitsilano Formation	Chuckanut Formation
	LOWER	Burrard Formation	
PALEOCENE		Lower Chuckanut	
		Upper Lasqueti Island beds	
CRETACEOUS	MAASTRICHTIAN	Gabriola Formation	Nanaimo Group
		Spray Formation	
		Geoffrey Formation	
		Northumberland Formation	
	CAMPANIAN	De Courcy Formation	
		Cedar District Formation	
		Extension-Protection Formation	
	SANTONIAN	Haslam Formation	
		Comox Formation	

Figure 1. Stratigraphic chart of the rock units in the Georgia-Whatcom basin being analyzed for palynology.

Vascular Plant Spores;

Laevigatosporites albertensis
L. discordatus
Azolla primaeva
Cicatricosisporites intersectus
Lygodium reticulosporites
Anemia poolensis

Pollen:

Pistillipollenites mcgregorii
Ludwigia trilobopollenites

5. Richfield wells and "South Westminster formation". **Miocene**. The most characteristic and abundant pollen include:

Pterocarya stellatus
Ulmipollenites undulosus

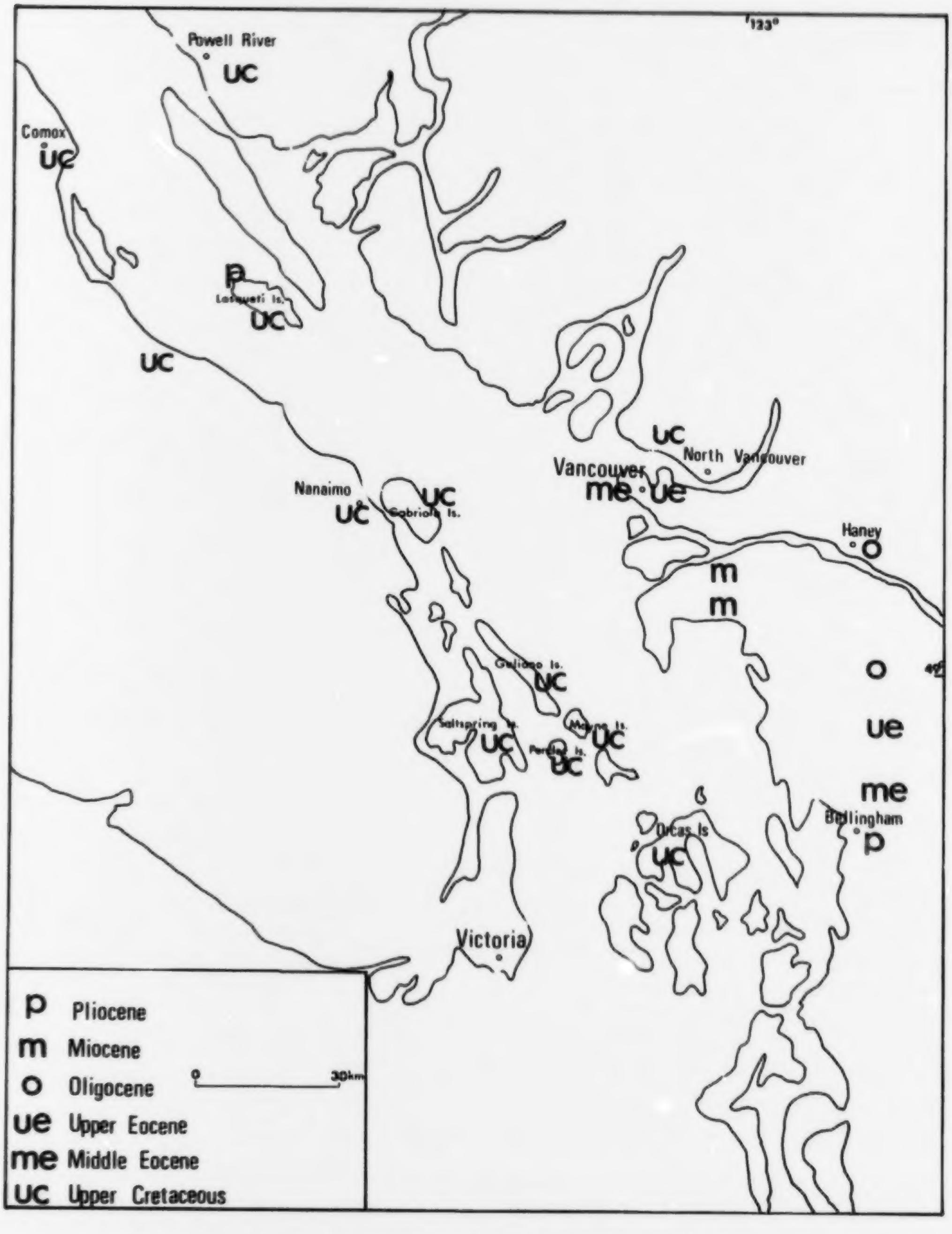
123°
Powell River
UC
Comox
UC
P
Lasqueti Is.
UC
UC
UC
North Vancouver
Vancouver
me
ue
Nanaimo
UC
UC
Gabriola Is.
Haney
O
m
m
O
49°
ue
me
Galiano Is.
UC
Saltspring Is.
UC
Mayne Is.
UC
Pender Is.
UC
Bellingham
p
Orcas Is
UC
Victoria
p Pliocene
m Miocene
o Oligocene
ue Upper Eocene
me Middle Eocene
UC Upper Cretaceous
0
30km

Figure 2. Palynological sampling sites and ages, Georgia-Whatcom basin

Liquidambar cf. *mangelsdorfiana*
Ilexpollenites iliacus
Glyptostrobus sp.

The "South Westminster formation" contains dinocysts; this information is being prepared for publication.

Sharp change in climatic conditions after Middle Miocene time led to a proliferation of conifers throughout Pliocene-Pleistocene time, with salt-marsh pollen occurring in the glacial phases of the sub-Fraser River deposits, and those on Panorama Ridge.

Future studies in this project will zero in on the Cretaceous of the east coast of Vancouver Island, the remaining Gulf Islands, and wells on both sides of the Canada-United States border.

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A new Frontier Geoscience Project: Chilcotin-Nechako region, central British Columbia[1]

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Hickson, C.J., A new Frontier Geoscience Project: Chilcotin-Nechako region, central British Columbia; in Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 115-120, 1990.

Abstract

The Chilcotin-Nechako region is underlain by the Stikine and Cadwallader terranes. Stikine rocks are thought to be the most extensive, but Jurassic (Toarcian) fossils found near Chilcotin River suggest that the Cadwallader Terrane extends northward beyond the Tyaughton-Methow Basin. The region experienced Late Jurassic emergence followed by an Early to mid-Cretaceous marine transgression. Black shale was found southeast of Tatla Lake, confirming the areal extent of the marine transgression. Late Cretaceous-early Tertiary emergence was followed by Eocene extension producing restricted, internally drained basins with nonmarine sediments and coal. The Mesozoic and Tertiary strata contain possible hydrocarbon source rocks.

Résumé

Le sous-sol de la région de Chilcotin-Nechako est constitué des terranes de Stikine et de Cadwallader. On pense que les roches de Stikine sont les plus importantes, mais des fossiles du Jurassique (Toarcien) découverts près de la rivière Chilcotin laissent supposer que le terrane de Cadwallader s'étend au nord au-delà du bassin de Tyaughton-Methow. La région a subi une émergence au Jurassique supérieur suivie d'une transgression marine entre le Crétacé inférieur et le Crétacé moyen. Au cours de l'été dernier, on a trouvé des schistes argileux noirs au sud-est du lac Tatla, ce qui confirme l'extension superficielle de la transgression marine. Une émergence survenue entre le Crétacé supérieur et le Tertiaire inférieur a été suivie d'une extension éocène qui a produit des bassins confinés, drainés intérieurement, renfermant des sédiments non marins et du charbon. Les couches du Mésozoïque et du Tertiaire renferment des roches mères d'hydrocarbures possibles.

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[1] Contribution to Frontier Geoscience Program

INTRODUCTION

Hydrocarbon exploration in the Chilcotin-Nechako region began in the 1930s and has continued intermittently since. Eight exploratory wells have been drilled and 1300 km of vibro-seismic data recorded. Well data indicate potential source and reservoir rocks but exploration interest has dwindled because the basic geological data and concepts of basin evolution and architecture are insufficient to pursue the work. This project aims to provide some of the missing data and to permit assessment of the hydrocarbon potential of the Chilcotin-Nechako region in central British Columbia (Fig. 1).

The project is part of a federal initiative to study regions which may have hydrocarbon potential. As such, the project is designed to meet the Frontier Geoscience Program (FGP) geological objectives to: 1) establish the deeper geological controls on the development of the sedimentary basin; 2) outline the internal geology and evolution of the basin; 3) elucidate the processes governing the generation, accumulation, and preservation of hydrocarbon resources; and 4) to identify and analyze hazards and constraints to development.

The Chilcotin-Nechako region, a physiographic subdivision of the southwestern Intermontane Belt, is underlain by the Stikine and Cadwallader terranes. Triassic to lower Tertiary crystalline rocks of the Coast Mountains form the western and southern boundary of the region. The eastern limit is the Fraser Fault and the northern boundary coincides with the Skeena Arch (Fig. 2). The area covers all or parts of map areas 92O, 92N, 93B to 93G, and 93J to 93L. Because the region is large, emphasis will be on the southern half. Anahim Lake (93C), Quesnel (93B), Taseko Lakes (92O) and the northeast corner of Mount Waddington (92N) are the areas of priority in this project.

The southern boundary of the region was the focus of recent detailed mapping in Taseko Lakes (92O) area (Glover and Schiarizza, 1987; Glover et al., 1987; McLaren, 1987; Garver et al., 1989; Schiarizza et al., 1989) by the staff of B.C. Geological Survey. This and other work provide a basis for extending and integrating structure and stratigraphy northward into the poorly exposed areas in the heart of the region. The region explored by Canadian Hunter Exploration Ltd. is included in the region to be studied and the company has generously provided access to samples and data collected during the course of their project.

Regional reconnaissance and related detailed studies were started during the summer of 1989. Preliminary findings are found in reports in this volume by Hunt and Bustin (1990) on the stratigraphy, organic maturation, and source rock potential of Cretaceous strata; Rouse et al. (1990) on a palynological and geochronological investigation of Mesozoic and Cenozoic rocks in the region; and van der Heyden (1990) on structural evolution of the western margin of the region.

EXPLORATION BACKGROUND

Koch (1973) produced the first study of potential oil- and gas-bearing basins in the Canadian Cordillera and assessed the regional geology and petroleum potential of the Whitehorse-Atlin, Bowser, Quesnel, and Nechako Tyaughton basins (Fig. 1). His estimate of the petroleu potential of the Nechako-Tyaughton Basin was 4-17.8 TC (trillion cubic feet) of gas.

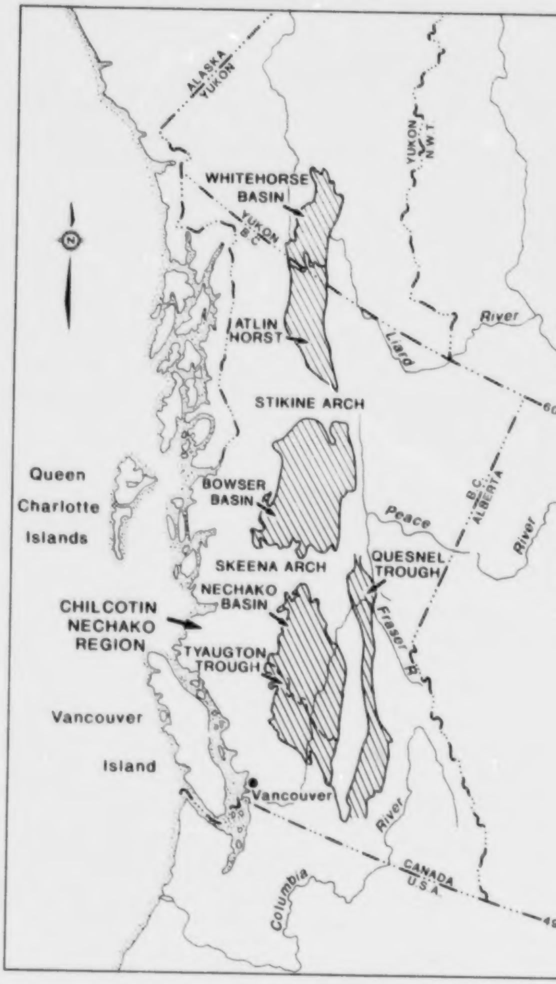

Figure 1. Schematic outline of the basins of the Canadia Cordillera (modified from Koch, 1973, Fig. 2).

The Chilcotin-Nechako region has been variousl referred to as the Quesnel Basin, and as the Nechako Basi and Tyaughton Trough (Koch, 1973; Fig. 1). A basin i generally considered to be an enclosed depression int which sediments accumulate. The Nechako Basin wa defined as a "shallow shelf area marginal to the deepe Tyaughton Trough. It contains Upper Cretaceous to Tertiary volcanics on the surface which unconformably overli Lower Cretaceous and Upper Jurassic [sediments]" (Koch 1973, p. 37). Since Koch's time the definition of th "Nechako Basin" has narrowed. It is a mid-Jurassic basi which evolved with the Bowser Basin from the Hazelto trough by uplift of the Skeena Arch. The Bowser Basin o the north contains strata of the Jurassic Bowser Lake Group the Nechako Basin in the south has sediments of the Ashma Formation (lower part of the Bowser Lake Group).

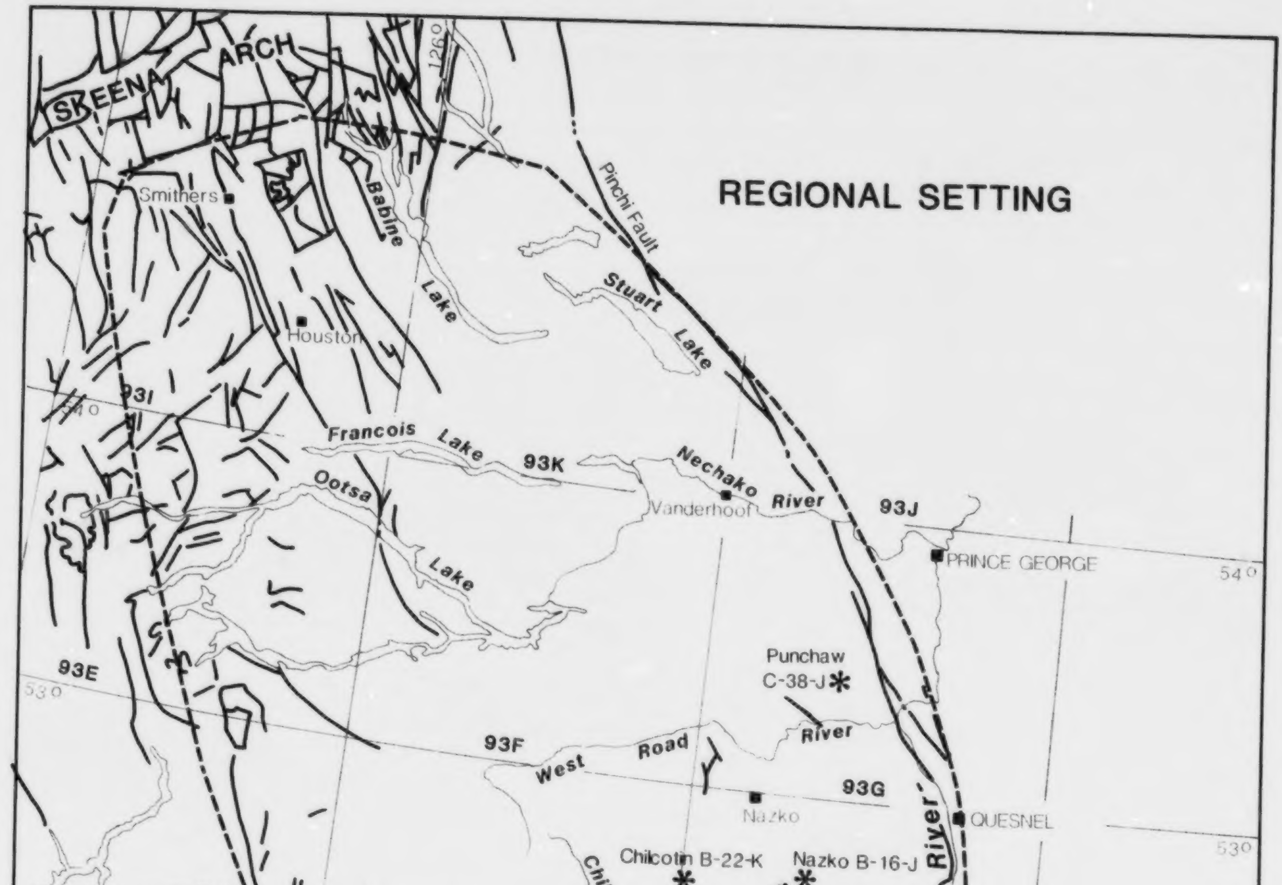
REGIONAL SETTING
SKEENA ARCH
Smithers
Houston
Babine Lake
Pinchi Fault
Stuart Lake
Francois Lake
Ootsa Lake
Nechako River
Vanderhoof
93I
93K
93J
PRINCE GEORGE
54°
93E
53°
Punchaw C-38-J
West Road River
93F
93G
Nazko
QUESNEL
Fraser River
Chilcotin B-22-K
Nazko B-16-J
Nazko D-96-E
Nazko A-4-L
Nazko B-48-C
Chilcotin River
Burke Channel
Bella Coola
Anahim Lake
93D
52°
Charlotte Lake
93C
93B
COAST MOUNTAINS
Harrison
Yalakom
Tchaikazan Fault
Tatla Lake
Redstone C-75-A
Alexis Creek
WILLIAMS LAKE
Chilco River
Redstone B-82-C
Redstone D-94-G
92N
92O
Faults and tectonic lineaments
Exploration wells
Lake - Pemberton
Chilco Lake
Churn Cr.
Fault
Hungry Valley Fault
Fraser Fault
122°
126°
124°
Bridge River Lineament
Lillooet
40 20 0
50 30 10 50
Scale km

Figure 2. Area covered by the Chilcotin-Nechako regional project showing the boundary as a dashed line, NTS grid, main faults (modified from Wheeler and McFeely, 1987), and hydrocarbon exploration wells.

Due to the uncertainty over what strata comprise the Nechako Basin, the word 'region' is used in preference to 'basin'. This wording is meant to reflect the importance of both the Jurassic 'Nechako Basin' strata and that of the poorly studied, discontinuous outcroppings of Cretaceous strata referred to as the 'Nazko Basin' (Fig. 3; Hunt and Bustin, 1990; Rouse et al., 1990) as well as Tertiary basins (Rouse and Mathews, 1990) within the Chilcotin-Nechako geographic area (Fig. 2).

The first hydrocarbon exploration well was drilled just outside the study area in 1932, but serious exploration did not begin until 1958. This investigation led to the 1960 drilling of two wells, Honolulu Nazko A-4-L (3159 m) and HB Redstone C-75-A (1307 m; Fig. 2), both into Cretaceous rocks. Detailed analyses of these holes by Canadian Hunter Exploration Ltd. confirmed light-oil stains in nine scattered zones totalling 85 m and the presence of source beds with sufficient organic content and thermal maturation.

Based on the detailed well analyses and a study of the region, a work bonus bid was undertaken by Canadian Hunter Exploration Ltd. for $27.5M (Oilweek, 1980). Four exploratory wells were drilled in 1981 (Redstone B-82-C, 524 m; Nazko D-96-E, 1013 m; Nazko B-16-J, 823 m; Kersley D-2-E, 405 m), one in 1982 (Chilcotin B-22-K, 2400 m) and a final hole in 1986 (Redstone D-94-G, 2165 m). Seismic and gravity surveys were also completed over the southeastern quadrant of the region as part of the program.

West of Vanderhoof, exploration carried out by Vital Pacific Resources Ltd., and kindly released to the GSC, identified a potential reservoir rock within mid-Albian lithic and quartz arenites of the Cretaceous Skeena Group and in an unnamed Permian(?) succession. A carbonate within this succession is a prolific oil-prone source rock with TOC (total organic carbon) values up to 5.6%. A second identified source rock, a mid-Albian shale, is regionally a moderate gas source rock with TOC values up to 1.5%. Locally, however, it is a rich oil-prone source rock with TOC values reaching 10.8%. Extracts from oil shows within the area yielded full hydrocarbon suites which indicated that they derive from a source rock in the main phase of hydrocarbon generation; they show no effects of thermal cracking (Vital Pacific Resources Ltd., unpublished data, 1988).

STRATIGRAPHIC FRAMEWORK OF THE REGION

Most of the Chilcotin-Nechako area is viewed as part of Stikinia (Monger and Berg, 1984). Triassic and Jurassic supracrustal and plutonic rocks assigned to Stikinia are dominantly marine arc volcanic and sedimentary rocks belonging to the Triassic Stuhini Group and the Lower to Middle Jurassic Hazelton Group (Fig. 3).

Within the region, the change from basin sedimentation (Bowser Lake Group) to emergent, predominantly volcanic conditions (Kasalka, Ootsa Lake, and Endako groups) took place at the end of the Jurassic. This emergence was followed by an Early to mid-Cretaceous marine transgression (Skeena Group, Fig. 3).

The western boundary of the study area is marked by Gambier Group rocks. These rocks are best exposed and studied in the Whitesail Lake area but age and lithological correlatives have also been found farther south (Fig. 3; van der Heyden, 1990).

The southwestern Chilcotin-Nechako region is underlain by Jurassic and Cretaceous supracrustal rocks of the Tyaughton-Methow Basin (Tyaughton Trough of Koch, 1973; Fig. 1; Jeletzky and Tipper, 1968; Tipper, 1969; Kleinspehn, 1985). These rocks are bounded to the west and south by the Coast Belt.

Much of the west-central Chilcotin-Nechako region appears to have a crystalline basement underlying the Mesozoic strata. High grade metamorphic rocks in the Tatla Lake area (Fig. 2) belong to an Eocene extensional core complex that may extend beneath much of the region (Friedman and Armstrong, 1988). During the development of the complex, mid-crustal rocks were deformed ductilely and then high-grade metamorphic rocks were denuded tectonically and exposed at the surface. Large grabens with thick accumulations of sedimentary rocks and organic matter were formed. Some of these basins yield coal —the Hat Creek Basin, southeast of the study area is an example.

RECENT FINDINGS

Outcrops of Cretaceous strata are sparse between the Tyaughton-Methow and Skeena basins. They have been reported in drillholes (Canadian Hunter Exploration Ltd., unpublished data, 1983), and during this field season outcrops of black shale of Cretaceous Hauterivian(?) age (J. Haggart, personal communication, 1989) were found southeast of Tatla Lake (Fig. 3). This area was previously thought to contain Jurassic Hazelton Group equivalents and unnamed Hauterivian and younger volcanics. Future work by Hunt and Bustin and others will help to correlate the isolated outcrops of Cretaceous strata. The question is whether they comprise one continuous, time-transgressive basin as suggested by H.W. Tipper (personal communication, 1989) or whether they are a series of small disconnected basins.

In the Tyaughton-Methow basin, outcrops of Cadwallader Group (Late Triassic Stuhini age-equivalents, Fig. 3) composed of limestone, greywacke, and pebble conglomerates are found. Similar limestones, near the Chilcotin River, were previously correlated with the Cache Creek Group (Monger and Berg, 1984). More recent findings suggest that these are Cadwallader Group equivalents (H.W. Tipper and G.J. Woodsworth, personal communication, 1989; Wheeler and McFeely, 1987; Gabrielse and Yorath, 1989). This summer's discovery of Jurassic (Toarcian, H.W. Tipper, personal. communication, 1989) black shale along the south side of the Chilcotin River provides evidence Cadwallader Terrane strata extend northward from the Tyaughton-Methow area. North of Chilcotin River (near Bald Mountain) we discovered an outcrop of ultramafic rock. Several

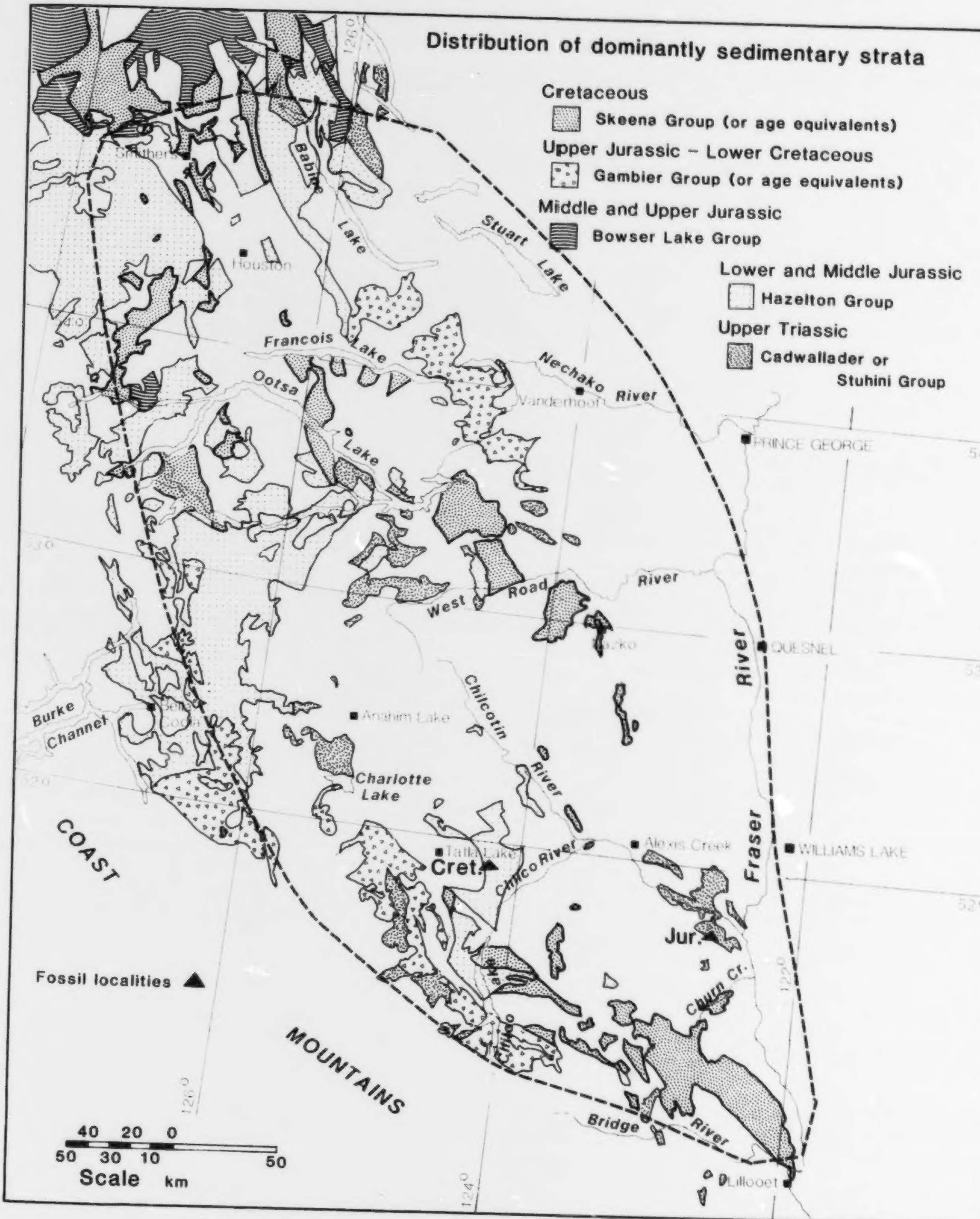
Distribution of dominantly sedimentary strata
Cretaceous
Skeena Group (or age equivalents)
Upper Jurassic - Lower Cretaceous
Gambier Group (or age equivalents)
Middle and Upper Jurassic
Bowser Lake Group
Lower and Middle Jurassic
Hazelton Group
Upper Triassic
Cadwallader or Stuhini Group
Smithers
Babine Lake
Stuart Lake
Houston
Francois Lake
Ootsa Lake
Nechako River
Vanderhoof
PRINCE GEORGE
54°
West Road River
Nazko
QUESNEL
53°
Fraser River
Chilcotin River
Burke Channel
Bella Coola
Anahim Lake
Charlotte Lake
COAST
MOUNTAINS
Tatla Lake
Cret.
Chilco River
Alexis Creek
WILLIAMS LAKE
52°
Jur.
Churn Cr.
Chilko
Fossil localities
Bridge River
Lillooet
126°
124°
122°
40 20 0
50 30 10 50
Scale km

Figure 3. Distribution of predominantly sedimentary strata within the Chilcotin-Nechako region (modified from Wheeler and McFeely, 1987). Bowser Lake Group strata are part of the Nechako Basin and Skeena Group rocks part of the Nazko Basin.

other outcrops of ultramafic rock have been found in this area by T.A. Richards (personal communication, 1989). These may represent the remnants of oceanic crust, preserved when Cadwallader Terrane was sutured to ancestral North America.

Regional gravity data for the study area hint at large throughgoing structures subparallel to the northwesterly tectonic strike. Gravity data obtained by Canadian Hunter Exploration Ltd. suggest a major fault near Alexis Creek (Canadian Hunter Exploration Ltd., unpublished data, 1983). In their interpretation, the structure trends northwest and has a large graben on its downthrown, west side. It is estimated that the graben contains a 6000 m thick section of sediments and terminates north of Alexis Creek. This structure lies almost equidistant between the Fraser and Yalakom faults (Fig. 2).

Regional low-level aeromagnetic data are incomplete over the basin. Limited magnetotelluric work to test crustal structure was carried out a few years ago in the Anahim Lake area under GSC contract. Preliminary analysis suggests that a similar graben may be present in the Dean River area (J.G. Souther, personal communication, 1988).

CONCLUSION

This project faces the problem of extensive cover of Pleistocene sediments and Tertiary lavas. On the positive side there is an extensive network of logging roads. These facts make the area a prime target for geophysical remote sensing methods. Regional magnetic, gravity, and seismic work will be needed to help interpret the geological data base in this region. Integration of such geophysical data with new geological maps will improve interpretations of the architecture and stratigraphy of the Chilcotin-Nechako region.

ACKNOWLEDGMENTS

The able and enthusiastic assistance of S. Higman in the office and field is most appreciated. Discussions with H.W. Tipper, P. van der Heyden, G.J. Woodsworth, and W.H. Mathews proved informative and instructive. Critical review by H.W. Tipper, D.J. Tempelman-Kluit, and G.J. Woodsworth was most appreciated. I also thank Canadian Hunter Exploration Ltd. and Vital Pacific Resources Ltd. for sharing unpublished information.

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Stratigraphy, organic maturation, and source rock potential of Cretaceous strata in the Chilcotin-Nechako region (Nazko Basin), British Columbia[1]

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Hunt, J.A. and Bustin, R.M., Stratigraphy, organic maturation, and source rock potential of Cretaceous strata in the Chilcotin-Nechako region (Nazko Basin), British Columbia; in Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 121-127, 1990.

Abstract

In the Chilcotin-Nechako region a highly varied succession of marine, transitional marine, and non-marine, coarse to fine grained clastic rocks outcrop. These strata define two basins: the Jurassic Nechako Basin and the Cretaceous Nazko Basin. The Nechako Basin is defined by rocks of the Ashman Formation of the Bowser Lake Group. The Nazko Basin includes rocks of the Skeena, Relay Mountain, Jackass Mountain, Taylor Creek, and Kingsvale groups and the Kitsun Creek Formation. Marine Cretaceous rocks occur throughout the Chilcotin-Nechako region, suggesting that the Cretaceous Nazko Basin may have extended from Smithers to the Methow Basin. The lateral extent of the Nechako Basin was probably similar to that of the Nazko Basin, extending from the Skeena Arch to the Tyaughton Trough. Preliminary studies indicate that the level of organic maturation and petroleum source rock quality is highly variable within the Chilcotin-Nechako region.

Résumé

Dans la région de Chilcotin-Nechako, il affleure une série très variée de roches marines, de transition et non marines, détritiques grain grossier à fin. Les couches définissent deux bassins, soit le bassin Jurassique de Nechako et le bassin crétacé de Nazko. Le bassin de Nechako est défini par des roches de la formation d'Ashman du groupe de Bowser Lake. Le bassin de Nazko renferme des roches des groupes de Skeena, de Relay Mountain, de Jackass Mountain, de Taylor Creek et de Kingsvale ainsi que la formation de Kitsun Creek. On trouve dans toute la région de Chilcotin-Nechako, des roches crétacées marines, ce qui laisse supposer que le bassin crétacé de Nazko peut s'être étendu de Smithers au bassin de Methow. L'étendue latérale du bassin de Nechako était probablement similaire à celle du bassin de Nazko, s'étendant de l'arche de Skeena à la dépression de Tyaughton. Des études préliminaires indiquent que le niveau de maturation organique et que la qualité des roches mères pétrolifères sont très variables dans la région de Chilcotin-Nechako.

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[1] Contribution to Frontier Geoscience Program

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INTRODUCTION

In the Intermontane belt of British Columbia, marine and transitional marine sedimentary strata of Jurassic and Cretaceous age lie within the Chilcotin-Nechako region (Hickson, 1990). The Jurassic sediments are part of the Nechako Basin, which is defined by the Upper Bajocian-Lower Oxfordian Ashman Formation of the Bowser Lake Group and rocks of the Jurassic Tyaughton Trough (Tipper and Richards, 1976). The younger sediments are part of a Cretaceous basin, herein referred to as the Nazko Basin, which occupies roughly the same area as the Nechako Basin and includes the Skeena and Methow basins of earlier studies (Hickson, 1990).

The Nechako Basin, as described by Tipper and Richards (1976), was formed in the mid-Jurassic when the emerging Skeena Arch divided the Hazelton Trough into two basins, the Bowser Basin to the north and the Nechako Basin to the south. Strata currently assigned to the Nechako Basin occupy a wedge-shaped area bounded on the north by the Skeena Arch, on the east by upper Paleozoic to mid-Jurassic(?) rocks of the Cache Creek Terrane and to t
west by Upper Jurassic to lower Tertiary rocks of the Co
Plutonic Complex and Jurassic and Cretaceous rocks of t
Tyaughton Trough (Tipper and Richards, 1976; Hickso
1990, Fig. 1). Sedimentation in the Nechako Basin was f
lowed by a period of uplift, and the Chilcotin-Necha
region was emergent by Late Jurassic time (Tipper a
Richards, 1976). Renewed subsidence in the Early Cre
ceous resulted in the formation of the Nazko Basin, whic
based on the known distribution of Cretaceous sedimen
likely extended from the Skeena Arch south to, a
included, the Methow Basin (Tipper and Richards, 197
Currently there is little evidence to show whether the Cre
ceous Nazko Basin was a single, large contiguous basin
a series of smaller sub-basins.

In order to refine the Cretaceous lithostratigraphy a
document the organic maturation and source rock quality
the Chilcotin-Nechako region, a field and laboratory stu
was begun. In the 1989 season, field work concentrated
the northern half of the Chilcotin-Nechako region a

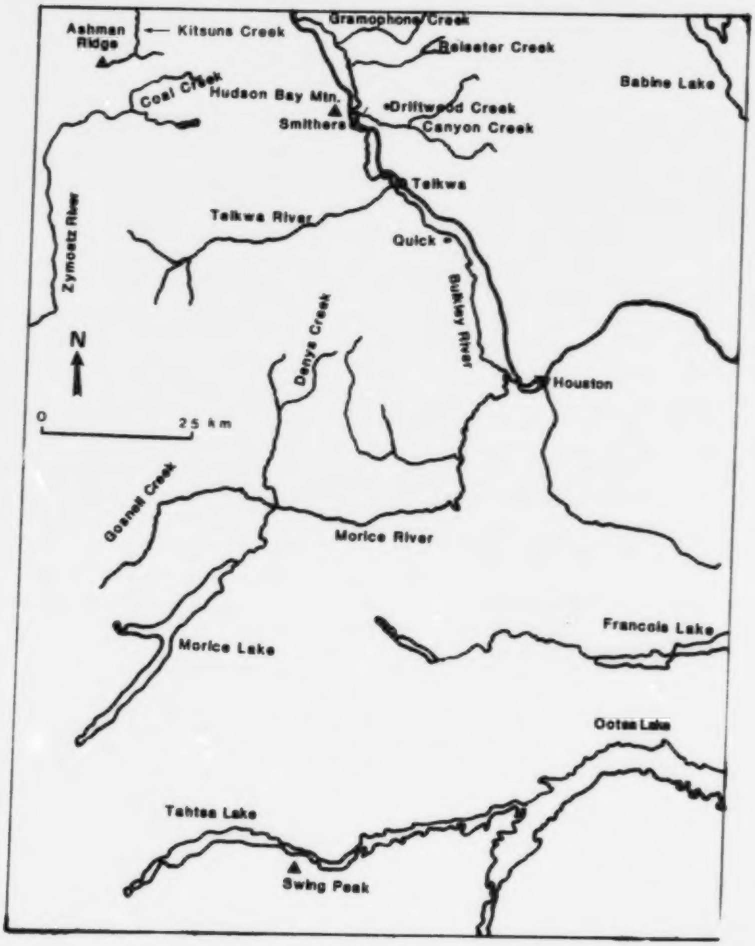

Ashman Ridge
Kitsuns Creek
Gramophone Creek
Reiseter Creek
Babine Lake
Coal Creek
Hudson Bay Mtn.
Smithers
Driftwood Creek
Canyon Creek
Telkwa
Telkwa River
Quick
Zymoetz River
Bulkley River
Denys Creek
N
Houston
0
25 km
Gosnell Creek
Morice River
Francois Lake
Morice Lake
Ootsa Lake
Tahtsa Lake
Swing Peak

Figure 1. Location map showing various features in the Smithers (93L) and northern Whitesail (93E) map areas.

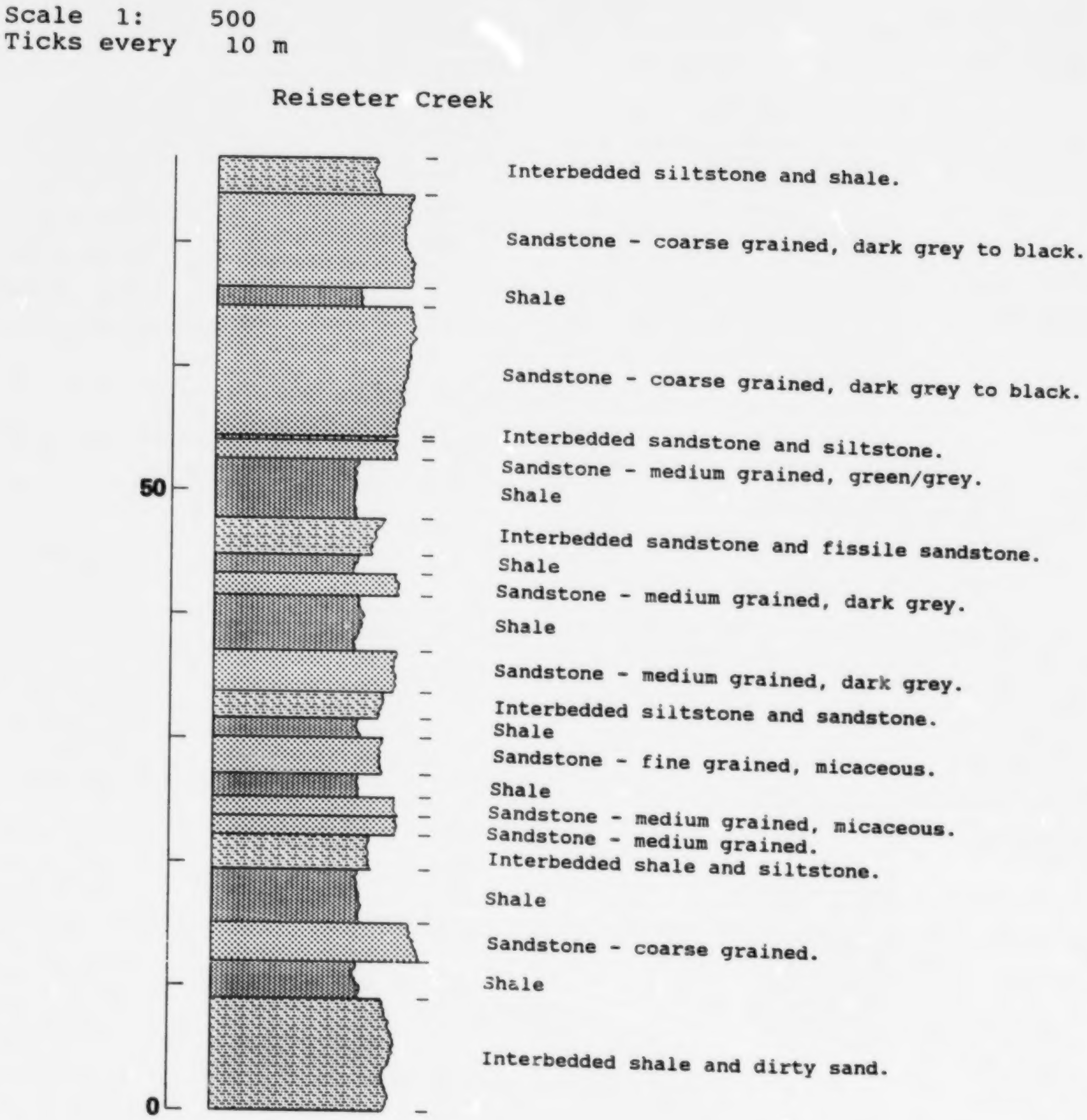

Scale 1: 500
Ticks every 10 m
Reiseter Creek
Interbedded siltstone and shale.
Sandstone - coarse grained, dark grey to black.
Shale
Sandstone - coarse grained, dark grey to black.
Interbedded sandstone and siltstone.
Sandstone - medium grained, green/grey.
50
Shale
Interbedded sandstone and fissile sandstone.
Shale
Sandstone - medium grained, dark grey.
Shale
Sandstone - medium grained, dark grey.
Interbedded siltstone and sandstone.
Shale
Sandstone - fine grained, micaceous.
Shale
Sandstone - medium grained, micaceous.
Sandstone - medium grained.
Interbedded shale and siltstone.
Shale
Sandstone - coarse grained.
Shale
Interbedded shale and dirty sand.
0

Figure 2. General stratigraphic section from Reiseter Creek, showing the nature of the Kitsun Creek Formation sediments; scale in metres.

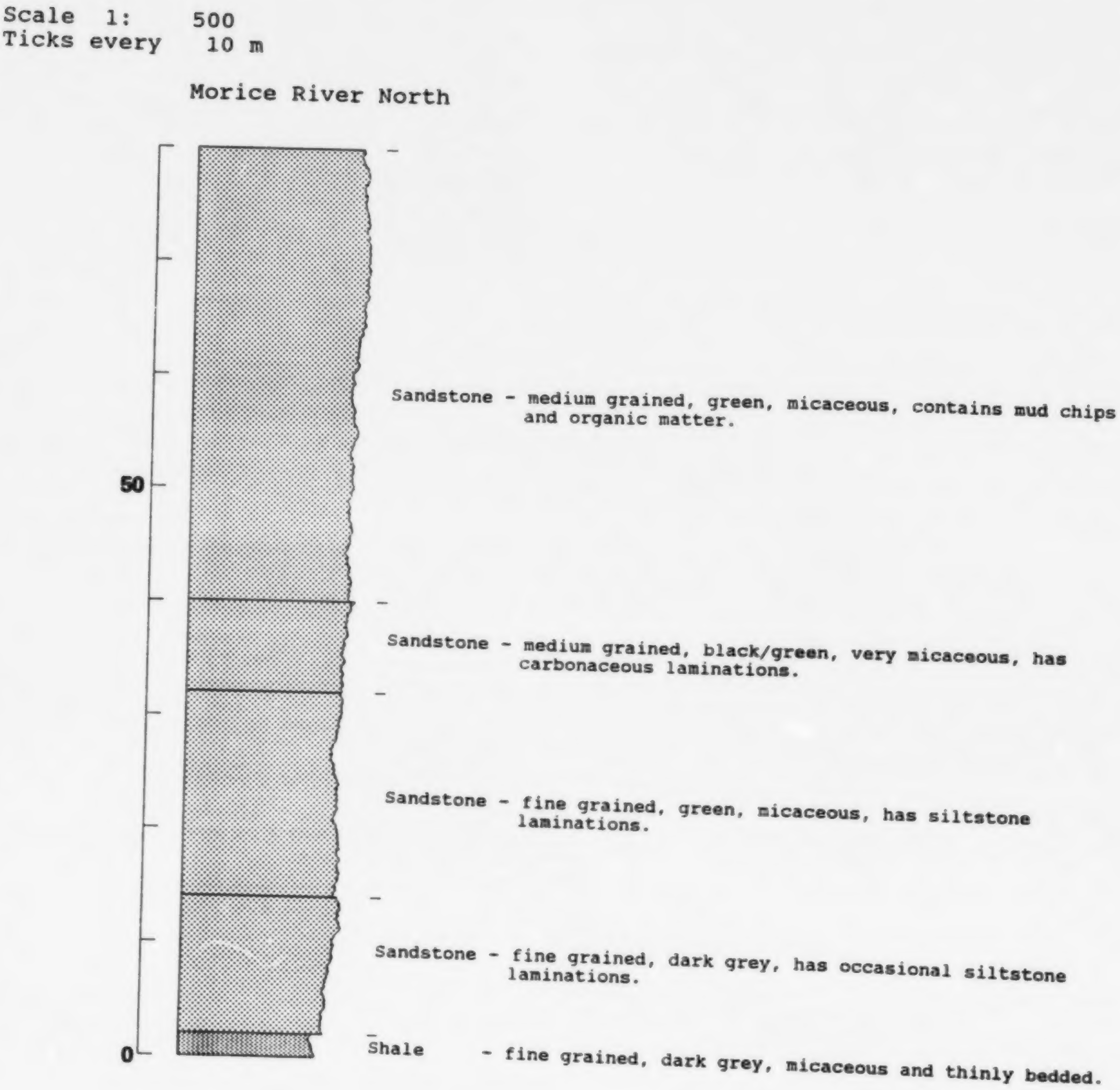

Scale 1: 500
Ticks every 10 m
Morice River North
50
0
Sandstone - medium grained, green, micaceous, contains mud chips and organic matter.
Sandstone - medium grained, black/green, very micaceous, has carbonaceous laminations.
Sandstone - fine grained, green, micaceous, has siltstone laminations.
Sandstone - fine grained, dark grey, has occasional siltstone laminations.
Shale - fine grained, dark grey, micaceous and thinly bedded.

Figure 3. General stratigraphic sections from the Morice River area showing the nature of the Skeena Group rocks; scale in metres. A) Morice River north; B) Morice River south.

extended from Smithers east to Prince George. Some work was carried out in the central and southern parts of the basin, specifically the Nazko area and further south in the Churn Creek and Chilko River areas (see Hickson, 1990, Fig. 2).

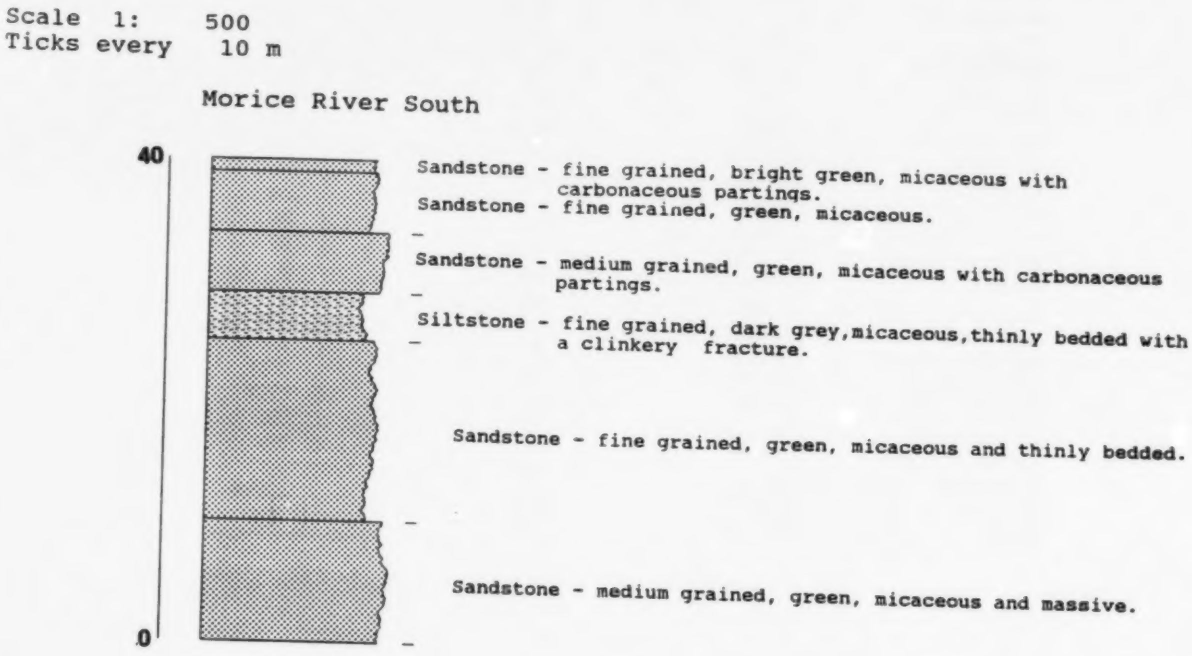
The study area comprises mainly low topography (swamp or ranch land) where outcrop is sparse, complicating stratigraphic interpretations. Strata have been preserved in down dropped fault blocks and exposed along creeks and roadcuts.

STRATIGRAPHY AND PETROLOGY

In the study area rocks of the Ashman Formation are poorly preserved and exposure is limited (Tipper and Richards, 1976). Most outcrops of the Ashman Formation in the Chilcotin-Nechako region are found in the Smithers map area (93L); fewer exposures occur in the Whitesail (93E), Nechako (93F) and Anahim Lake (93C) map areas (see Hickson, 1990; Fig. 3). The best exposure in the Chilcotin-Nechako area, occurs about 40 km northwest of Smithers on Ashman Ridge (Fig. 1). Here, a continuous section 900 m thick is exposed (Tipper and Richards, 1976). The section coarsens upwards, with thin bedded argillites at the base grading upwards into interbedded argillite and sandstone which in turn, grade up to interbedded sandstone and conglomerate. Argillites within the section on Ashman Ridge are up to 50 m thick. Individual argillite beds average 30 cm in thickness, are black and very fine grained, and commonly contain belemnites. Sandstone of the Ashman Formation ranges from coarse to fine grained and varies in thickness from 1-4 m. Individual beds range from 5-15 cm in thickness. The finer grained sandstone commonly contains carbonized wood fragments. Conglomerate beds average 7 m in thickness and fine upward. Clasts average 10 cm in diameter at the base of the beds, grading upward to laminated fine grained dark grey sandstone. The conglomerate is poorly sorted and the clasts are subangular to subrounded; 60 % of the clasts are volcanic, 30 % are quartz, and 10 % are chert.

Rocks mapped as Kitsun Creek Formation and Skeena Group (Tipper, 1978), define the northern portion of the Nazko Basin. These rocks are better exposed than those of the Ashman Formation. They are preserved in down dropped fault blocks (Tipper and Richards, 1976) and exposed in creeks or roadcuts. In the study area, thick sections of strata assigned to the Kitsun Creek Formation occur in Kitsun, Gramophone, and Reiseter creeks (Fig. 1, 2). The formation varies from coarse to fine grained heterolithic conglomerate (up to 15 m thick), to fine to coarse grained sandstone (1-10 m thick), containing carbonized wood fragments, to dark grey, highly fissile, carbonaceous shale and minor coal (especially in the Coal Creek area, Fig. 1).

In the Smithers area, the Skeena Group shows significant lateral and vertical variation. Lithologies within the Skeena Group range from conglomerate to fine grained sandstone, siltstone, mudstone, shale, and coal. Finer grained units, in the Smithers map area, commonly contain marine bivalves and are overlain by volcanic rocks of the Brian Boru Formation. To the south, in the Whitesail map area, the Skeena sediments are overlain by volcanic rocks of the Kasalka and Ootsa Lake groups (Woodsworth, 1980). The most commonly exposed strata of the Skeena Group is sandstone with beds varying from 1 cm to 5 m thick. Skeena Group sandstone is green, micaceous, contains carbonized wood fragments, and is generally massive, rarely showing any sedimentary structures.


Scale 1: 500
Ticks every 10 m
Morice River South
40
0
Sandstone - fine grained, bright green, micaceous with carbonaceous partings.
Sandstone - fine grained, green, micaceous.
Sandstone - medium grained, green, micaceous with carbonaceous partings.
Siltstone - fine grained, dark grey,micaceous,thinly bedded with a clinkery fracture.
Sandstone - fine grained, green, micaceous and thinly bedded.
Sandstone - medium grained, green, micaceous and massive.

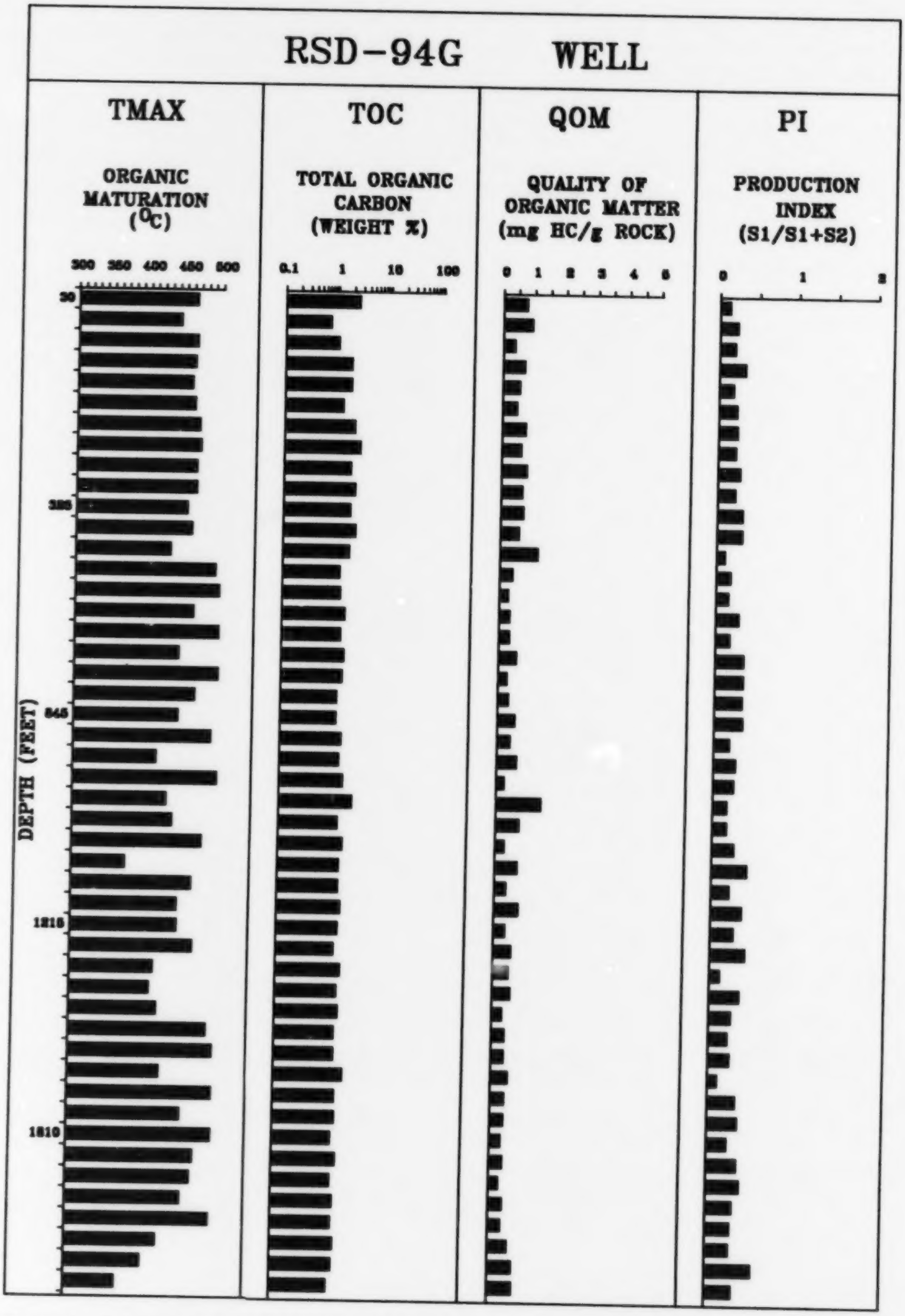


Figure 4. Rock-Eval logs for the Redstone d-94-G(92-0-12) well. Quality of organic matter (QOM = (S1 + S2)/TOC), PI = Production Index (S1/[S1 + S2]). Well location is shown in Hickson (1990, Fig. 2).

About 20 km south of Smithers, the thickest known section of Skeena Group is preserved in the Telkwa Basin near Telkwa (Fig. 1). This section, approximately 500 m thick, consists of interbedded siltstone, mudstone, shale, and fine sandstone, containing up to ten coal seams which vary in thickness from 0.5-7.0 m (R.J. Palsgrove, personal communication, 1989). This fine grained sequence grades laterally eastward into coarser grained sandstone; to the west in the Denys Creek area fine grained sandstone, shale, and coal outcrop (Fig. 1).

Southwest of Houston in the Morice River area, the Skeena Group consists of sandstone and shale. The sandstone is medium to fine grained and varies in thickness from 1-40 m. Dark grey to green shale forms recessive intervals 0.5-5 m thick (Fig. 3). Farther south on Swing Peak (Fig. 1) sandstone of the Skeena Group is preserved in a collapsed caldera (MacIntyre, 1985).

Within the Skeena Group, chert-pebble conglomerate is rarely seen. The two known locations in the Smithers map area (93L) are Hudson Bay Mountain and Gosnell Creek. Here the conglomerate varies in thickness from 0.8-6 m and is composed of clasts which average 10 cm in diameter; approximately 60 % of the clasts are composed of chert, the remaining clasts are sedimentary or volcanic in origin.

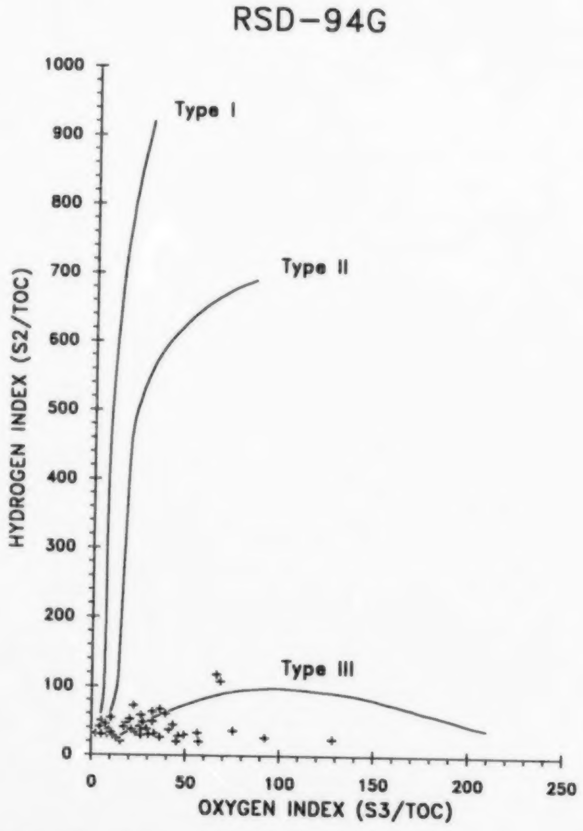


Figure 5. Hydrogen index versus oxygen for the Redstone D-94-G (92-0-12) well. Diagenetic pathways for the three main kerogen types are shown (see Tissot and Welte, 1984).

The southern portion of the Cretaceous Nazko Basin comprises rocks of the Middle Jurassic to Lower Cretaceous Relay Mountain Group, the Lower Cretaceous Jackass Mountain and Taylor Creek groups, and the Upper Cretaceous Kingsvale Group (Tipper, 1978). In the central part of the Nazko Basin exposures are poor, and the Cretaceous strata are unnamed (see Hickson, 1990, Fig. 3). These sediments were only briefly examined during the 1989 field season.

ORGANIC MATURATION AND PETROLEUM SOURCE ROCK QUALITY

In order to assess the organic maturation and source rock potential of strata in the Nazko Basin, outcrop samples were collected from representative lithologies. Well cuttings from petroleum exploration holes were also obtained. Preliminary results of Rock-Eval pyrolysis and total organic carbon analyses (TOC) from the Redstone D-94-G(92-0-12) well are summarized in Figures 4 and 5. Based on Tmax, the strata appear for the most part to be over mature with respect to oil generation. Most samples from this well have TOC values ranging from 1-3 % and generally have low quality and production indexes. Other wells from the Nazko and Redstone areas remain to be studied.

FUTURE WORK

Additional field studies are required to document the distribution and refine the lithostratigraphy and biostratigraphy of Cretaceous strata, particularly in the central and southern parts of Chilcotin-Nechako area. Future studies will include laboratory analysis to access the petroleum source rock potential and inorganic petrology to define further the lithostratigraphy, provenance and petroleum reservoir potential of the strata.

ACKNOWLEDGMENTS

This study forms part of the Chilcotin-Nechako Frontier Geoscience Project. Funding was provided through an EMR Research Grant and NSERC Grant A7337 to R.M. Bustin. Many thanks are extended to Pat Desjardins, Don MacIntyre, Les Lyons, and Marylou Mallot of the British Columbia Geological Survey for their help throughout the summer. Field assistance was ably provided alternately by Clara Davis and Eva Bergmansen. We would like to thank Dave and Briget Gillespie, Derk Albers, and the Bradfords for their concern and hospitality. Informative discussions with Cathie Hickson, Tom Richards, and Howard Tipper were much appreciated. We thank Cathie Hickson and G.J. Woodsworth for their review of this report. Lastly, we would like to thank Regan Palsgrove for her help and support throughout the summer.

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A palynological and geochronological investigation of Mesozoic and Cenozoic rocks in the Chilcotin-Nechako region of central British Columbia[1]

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Rouse, G.E., Mathews W.H., and Lesack K.A., A palynological and geochronological investigation of Mesozoic and Cenozoic rocks in the Chilcotin-Nechako region of central British Columbia; in Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 129, 133, 1990.

Abstract

In the Chilcotin-Nechako region, palynomorphs have been recovered from Cretaceous, Tertiary, and Pleistocene strata. New mapping in Churn Creek has outlined a sequence of volcanics overlain by mid-Cretaceous fluviatile sediments that are structurally overlain by flows and breccia.

Résumé

Dans la région de Chilcotin-Nechako, on a découvert des palynomorphes dans des couches crétacées, tertiaires et pléistocènes. Un nouveau levé géologique effectué dans la région de Churm Creek a permis de délimiter une série de roches volcaniques recouvertes de sédiments fluviatiles du Crétacé moyen qui sont structuralement recouverts de coulées et de brèches.

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INTRODUCTION

This project is being undertaken to determine the ages of the surface and subsurface rock units of the combined Chilcotin-Nechako basins of central British Columbia (Hickson, 1990). Secondary objectives are to determine the TAI values (Thermal Alteration Index) and the reconstruction of paleoclimates as indices of possible hydrocarbon generation. This is an extension of previous investigations into the ages and distribution of Cretaceous and Cenozoic rock units (e.g. Rouse and Mathews, 1961, 1979, 1988, 1989; Rouse, 1977; Mathews, 1964; and Mathews and Rouse, 1963, 1986). The summary ages of the palynoassemblages and K-Ar determinations available to date (Fig. 1 and 2) range from Albian on Churn Creek southwest of Gang Ranch to Pleistocene near Dog Creek east of Fraser River.

GEOLOGY OF THE MIDDLE CHURN CREEK VALLEY

Geological mapping of the middle Churn Creek valley (Fig. 2) was undertaken primarily to clarify the stratigraphy and structure of Cretaceous beds in the area. This work is an extension to the west of previous mapping on lower Churn Creek (Mathews and Rouse, 1984) and a revision of reconnaissance mapping by Tipper (1978).

The oldest rocks are maroon to green, badly fractured lavas and pyroclastic rocks exposed in the core of a doubly-plunging anticline along Churn Creek.

These volcanic rocks are overlain by some 300 m of tan sediments, mostly pebble conglomerate and sandstone from which a mid-Cretaceous palynoassemblage has been recovered (Mathews and Rouse, 1984). The sediments are thick-bedded, moderately well sorted, and rich in chert and volcanic debris. Carbonaceous detritus is uncommon. Cross-bedding is widespread. A fluviatile origin and an easterly or northerly source are probable. On the north flank of the anticline the upper part of the sedimentary succession apparently gives way westerly to a massive ill-sorted lahar and volcanic conglomerate; a facies change rather than an unconformity or cross-faulting is inferred.

The sedimentary beds are ringed by structurally higher lavas and volcanic breccias characterized by phenocrysts of feldspar and hornblende with or without biotite. Local faulting parallel to the base of this unit is indicated but the general anticlinal structure persists upward.

Eocene lavas, some of which also contain hornblende phenocrysts, rest with no obvious unconformity on the feldspar-hornblende porphyries of the north flank of the anticline where they exhibit moderate north dips and form south-facing cuestas.

The dominant structure is a single, broad, doubly plunging anticline extending at least 12 km, and possibly 18 km, in a northeast-southwest direction nearly perpendicular to the regional structural trend in the surrounding areas. Dips of the bedding are typically less than 30°. Postdepositional faulting does not appear to have played a significant role in the present-day distribution of the rock units in this area.

Rare scarps of columnar basalt flows, backed by nea level plateaus, and many large basalt blocks in the dr indicate a widespread cover of Neogene Chilcotin lava the north and west parts of the area mapped.

CENOZOIC LOCALES AND PALYNOASSEMBLAGES

Known Cenozoic localities and palynoassemblage in t Chilcotin-Nechako region are shown in Figure 1. The range from extensive Middle Eocene outcrops a palynoassemblages of which several have been described Rouse and Mathews (1961, 1988) and Mathews and Rou (1986), to Pleistocene (Mathews and Rouse, 1986). List below are selected lists of the more important palynomorp for the Cenozoic deposits shown in Figure 1.

Middle Eocene: The most representative palynomorp from the Middle Eocene deposits (Rouse and Mathew 1988; plate 2) are:

Pollen and Spores:
- *Pistillipollenites mcgregorii P.* sp.
- *Tilia crassipites*
- *T. vescipites*
- *Fothergilla vera*
- *Gothanipollis eocenicus*
- *Platycarya* cf. *swasticoida*
- *Rhoipites latus*
- *Symplocoipollenites* sp.

Fungal Spores:
- *Multicellaesporites*-b
- *Diporisporites* sp. A
- *Pluricellaesporites psilatus*

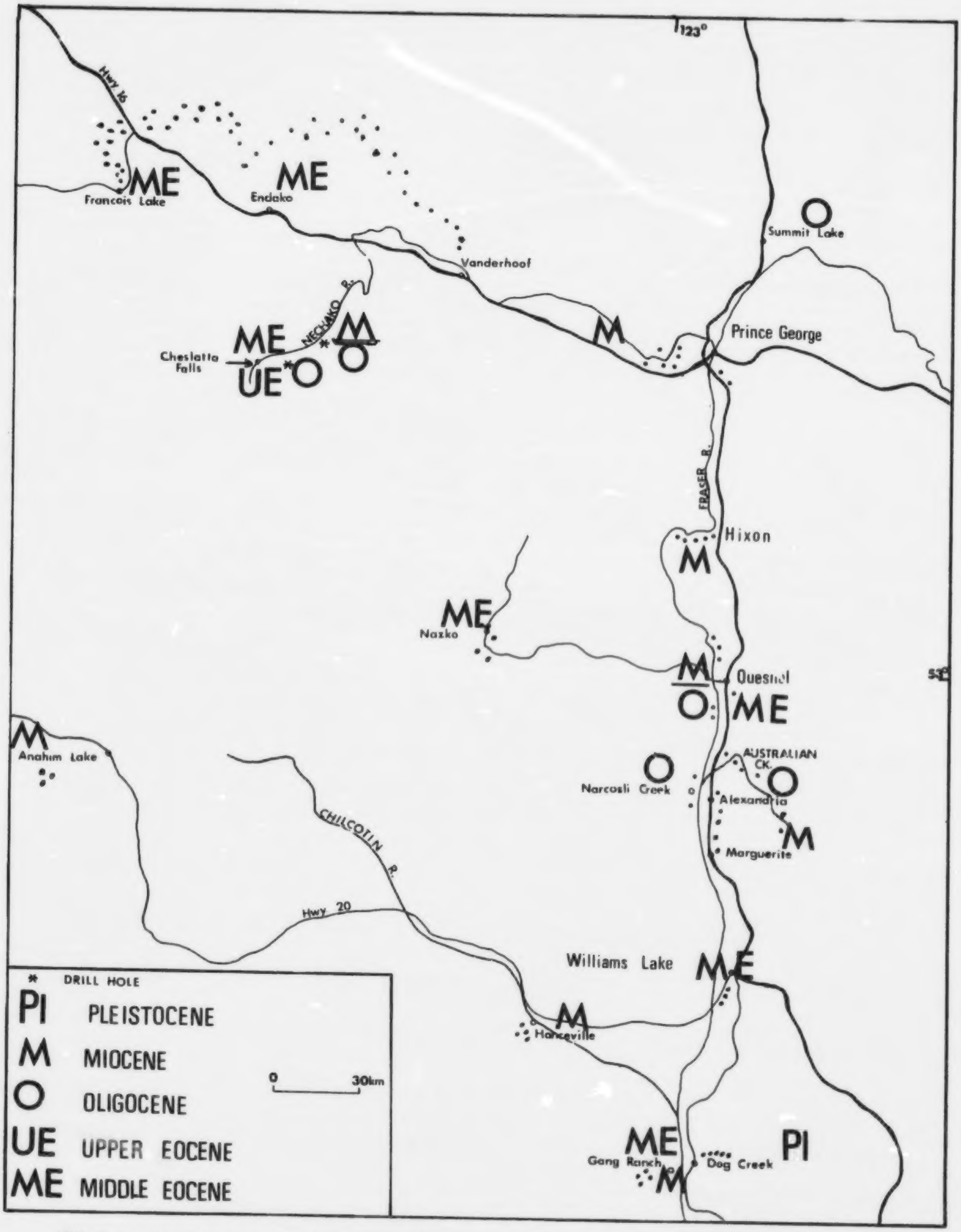
Upper Eocene: The most representative palynomorph from the Cheslatta beds (Rouse and Mathews, 1988) are

Pollen and Spores:
- *Rousea araneosa*
- *Tricolporopollenites* sp. A
- *Cupaneidites* n. sp.
- *Liliacidites tritus*
- *Lymingtonia* cf. L. *shator*
- *Araliaceoipollenites profundus*
- *A. granulatus*
- *A. megaporifer*
- *Tetracolporopollenites lesquereuxianus*

Fungal Spores:
- *Dicellaesporites obnixus*
- *Granatisporites catinus*
- *G. cotalus*
- *Inapertisporites circularis*
- *I. ovalis*
- *Pesavis tagluensis*
- *Pluricellaesporites psilatus*

Tetracellate spores

Oligocene: Outcrops of the Australian Creek Formation south of Quesnel and equivalent subsurface sediments from southwest of Vanderhoof (Rouse and Mathews, 1989) con-



123°
Hwy 16
ME
Francois Lake
ME
Endako
Vanderhoof
O
Summit Lake
Prince George
NECHAKO R.
M
ME
M
Cheslatta Falls
UE
O
O
FRASER R.
Hixon
M
ME
Nazko
M
O
Quesnel
ME
53°
M
Anahim Lake
O
Narcosli Creek
AUSTRALIAN CK.
O
Alexandria
M
Marguerite
CHILCOTIN R.
Hwy 20
Williams Lake
ME
M
Hanceville
ME
Gang Ranch
M
Dog Creek
PI
0
30km
* DRILL HOLE
PI PLEISTOCENE
M MIOCENE
O OLIGOCENE
UE UPPER EOCENE
ME MIDDLE EOCENE

Figure 1. Location map showing the sampling sites for the five Cenozoic horizons in the Chilcotin-Nechako basin.

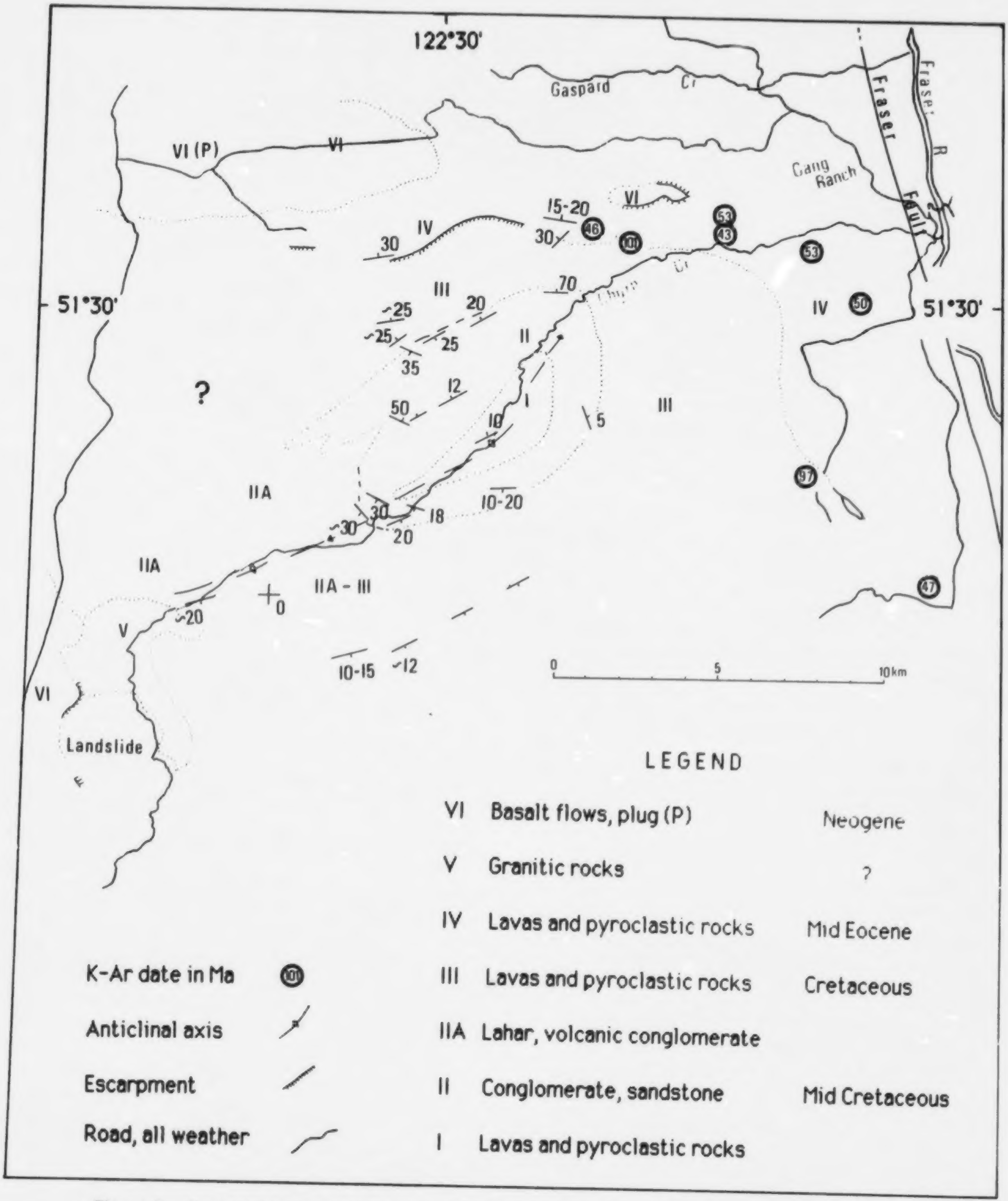

122°30'
Gaspard Cr
Fraser R
Fraser Fault
Gang Ranch
Churn Cr
VI (P)
VI
VI
IV
IV
III
III
II
IIA
IIA
IIA - III
I
V
VI
?
51°30'
51°30'
Landslide
15-20
30
30
70
20
25
25
25
35
12
50
10
5
10-20
18
30
30
20
0
20
10-15
12
46
100
53
43
53
50
97
87
0
5
10km
LEGEND
VI Basalt flows, plug (P) Neogene
V Granitic rocks ?
IV Lavas and pyroclastic rocks Mid Eocene
III Lavas and pyroclastic rocks Cretaceous
IIA Lahar, volcanic conglomerate
II Conglomerate, sandstone Mid Cretaceous
I Lavas and pyroclastic rocks
K-Ar date in Ma 100
Anticlinal axis
Escarpment
Road, all weather

Figure 2. Geological map of Middle Churn Creek Valley. Radiometric dates from Mathews and Rouse (1984).

tain typical Oligocene palynoassemblages. The most diagnostic palynomorphs are:

Pollen and Spores:
  Boisduvalia clavatites
  Jussiaea sp.
  Diervilla echinata
  Parviprojectus - A.
  Podocarpus biformis

Fungal Spores:
  Pesavis tagluensis
  Ctenosporites wolfei

Miocene: The Fraser Bend Formation, described by Rouse and Mathews (1979) from the large S-shaped bend on the Fraser River just upstream from Quesnel, yielded a rich palynoassemblage. The same rocks, ranging from clays to volcaniclastics, and containing the same palynoassemblages have been found from the Highland Valley in the south, through Deadman River, to the Chilcotin River region, through to Quesnel, to the Prince George-Vanderhoof area, and northward to south of Babine Lake. The main Middle Miocene palynomorphs are:

Pollen and Spores:
  Cedrus perialata
  Tsuga igniculus
  Quercoidites microhenricii
  Juglans periporites
  Lycopodium foveolites
  Metasequoia papillapollenites
  Monulcipollenites confossus

Pleistocene: Early Pleistocene sediments have been recognized and described at Dog Creek (Fig. 1; Mathews and Rouse, 1986) and recognized recently in Empire Valley (south of the area of Fig. 1) just west of the Fraser Fault. These deposits appear to indicate proglacial conditions, with a relatively depauperate palynoassemblage, including:

Pollen and Spores:
  Pinus - diploxylon type
  cf. *Pinus contorta*
  Picea grandivescipites
  Tsuga heterophyllites
  Abies sp.
  Chenopodipollis spp.
  Artemisia sp.
  Myrica sp.
  Quercoidites sp.
  Graminidites sp.

This assemblage was interpreted as representing a tundra-type vegetation associated with early Pleistocene glaciations reported in other areas of the Pacific Northwest (Mathews and Rouse, 1986).

The plans for ongoing research on the combined Nechako and Chilcotin basins include sampling composites at 50 m intervals from two deep wells. One is Canadian Hunter et al. Nazko D-96-E (1013 m), which will give a good record of the palynomorphs, TAI values, and kerogen types for the Nechako Basin. The other is Canadian Hunter et al. Chilcotin B-22-K to a depth of 2400 m; which will provide a complete picture of the stratigraphy, thermal maturation picture, and paleoenvironmental reconstruction of the northern basin.

ACKNOWLEDGMENTS

We wish to thank Dr. Cathie Hickson of the Geological Survey of Canada, for initiating and supporting this project. We are also grateful to the owners and operators of Gang Ranch and Empire Valley Ranch, for permission to enter their lands and other courtesies. We also wish to thank Black Dome Mining Company for access to cores and samples. Trevor Cattermole served very effectively as a field assistant. Thanks are extended to Mr. Charlie Boitard of Menika Mining Ltd. (N.P.L.), for samples from his gold prospecting cores west of the Deadman River.

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Structural style and stratigraphy of southwest Spatsizi map area, British Columbia[1]

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Evenchick, C.A. and Green, G.M., Structural style and stratigraphy of southwest Spatsizi map area, British Columbia; in Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 135-144, 1990.

Abstract

Western Spatsizi map area is underlain by Lower to Middle Jurassic Hazelton Group, Lower to Middle Jurassic Spatsizi Group, and Middle Jurassic to Cretaceous(?) Bowser Lake Group. Most of the area is underlain by the Bowser Lake Group, which consists of sequences of clastic sedimentary rock similar to those mapped to the east, including Ashman Formation at the base, and associated turbidites. Shallow marine strata with abundant conglomerate and coarsening-up sequences (some with coal), and nonmarine sequences are also present.

The style and intensity of folds resemble those in eastern Spatsizi map area; however, the variations in axial surface trends and the interference of folds contrast with the dominant northwest trends and rare interference of folds observed to the east. Folded Bowser Lake Group is overlain by Pliocene columnar basalt flows, informally called the Maitland volcanics.

Résumé

Le sous-sol de la région levée de Spatsizi ouest est constitué du groupe de Hazelton datant du Jurassique inférieur à moyen, du groupe de Spatsizi datant du Jurassique inférieur à moyen et du groupe de Bowser Lake datant du Jurassique moyen au Crétacé (?). Le sous-sol de la majeure partie de la région est constitué du groupe de Bowser Lake qui consiste en séries de roches sédimentaires détritiques similaires à celles qui ont été cartographiées à l'est; il comprend la formation d'Ashman à sa base et des turbidites associées. Des couches marines peu profondes sont accompagnées d'abondantes séries de conglomérats et à grand classement inverse (certaines accompagnées de charbon) de séries non marines.

Le style et l'intensité des plis ressemblent à ceux qu'on trouve dans la région levée de Spatsizi est. Toutefois, les variations des directions axiales superficielles et interférence des plis contraste avec les directions prédominantes nord-ouest et les rares interférences des plis observées à l'est. Le groupe plissé de Bowser Lake est recouvert de coulées de basalte prismatique, connu sous le nom plus familier de roches volcaniques de Maitland.

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INTRODUCTION

This work is part of a long-term project designed to understand the depositional, structural, and thermal history of the northern Bowser Basin. Results of the first four seasons of field work, and reviews of the regional geology were given by Evenchick (1986, 1987, 1988, 1989). The most recent regional map was published by Gabrielse and Tipper (1984).

The Bowser Basin occupies 50 000 km^2 of north-central British Columbia (Fig. 1). The Jurassic and Lower Cretaceous marine and nonmarine clastic sedimentary fill of the basin is called the Bowser Lake Group (Tipper and Richards, 1976). The basin is bounded on the west and north by island arc volcanics of the Lower to Middle Jurassic Hazelton Group, and on the east by nonmarine sedimentary rock of the Cretaceous Sustut Group (Fig. 1). The Spatsizi Group is a thin but regionally mappable unit between the Bowser Lake and Hazelton groups. Strata of the Hazelton, Spatsizi, Bowser Lake, and Sustut groups are intensely folded and faulted, resulting in structural contacts between the Bowser Basin and its bounding units. Deformation occurred in latest Jurassic(?) to latest Cretaceous time, forming a fold belt more than 200 km across strike, with northeasterly shortening locally up to 50% (Evenchick, 1988, 1989).

Geological mapping in the summer of 1989 concentrated on the area between the Little Klappan River and the south and west boundaries of Spatsizi map area (Fig. 1). The Bowser Lake Group occupies much of the area, and in the north is in stratigraphic contact with the underlying Spatsizi Group. The Bowser Lake Group here includes turbidites, nonmarine strata, and shallow marine clastic sedimentary rock, some with intercalated coal seams. The style, orientation, and scale of folding of Bowser Lake Group vary remarkably. Folded Bowser Lake Group is overlain by erosional remnants of basaltic flows of Early Pliocene age informally called the Maitland volcanics (Souther, in press).

As of April 1989, the project is funded by the Frontier Geoscience Program, an Energy Mines and Resources initiative to understand the geological evolution of sedimentary basins. Specifically, the objectives are (1) to gain controls on the deep geological structure, (2) to elucidate the internal geology and evolution of basins, (3) to understand processes governing the generation, accumulation, and preservation of hydrocarbons, and (4) to identify hazards and constraints to development. In the case of the Bowser Basin project, the mandate is to continue developing a regional structural and stratigraphic framework for the northern Bowser Basin, and to collect, interpret, and present data pertaining to the thermal maturation of the northern part of the basin. Other contributions associated with this project are those of Cookenboo and Bustin (1990), and Ricketts (1990).

STRATIGRAPHY

Figure 2 shows the distribution of the four regional stratigraphic units: the Hazelton, Spatsizi, and Bowser Lake

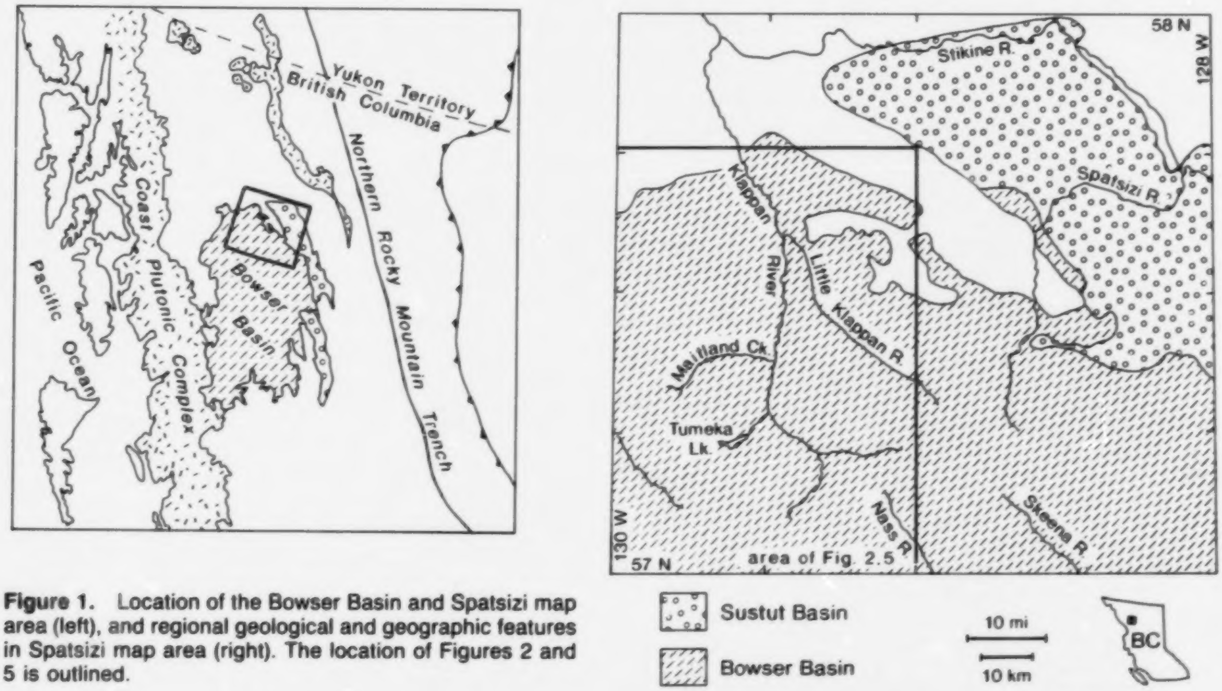


Figure 1. Location of the Bowser Basin and Spatsizi map area (left), and regional geological and geographic features in Spatsizi map area (right). The location of Figures 2 and 5 is outlined.

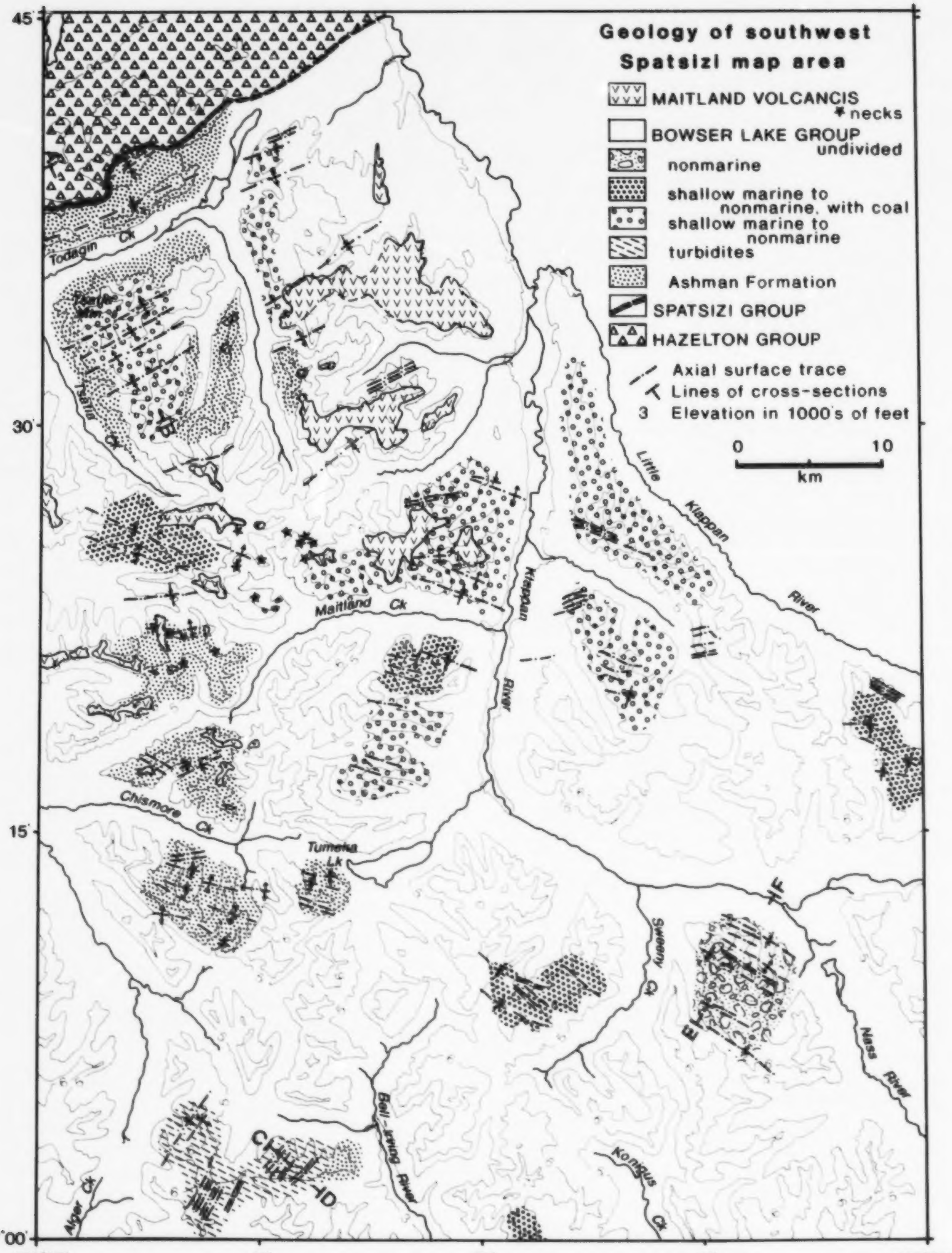

Geology of southwest
Spatsizi map area
MAITLAND VOLCANCIS
necks
BOWSER LAKE GROUP
undivided
nonmarine
shallow marine to nonmarine, with coal
shallow marine to nonmarine
turbidites
Ashman Formation
SPATSIZI GROUP
HAZELTON GROUP
Axial surface trace
Lines of cross-sections
3 Elevation in 1000's of feet
0
10
km
Todagin Ck
Tsatia Ck
B
Little Klappan River
Maitland Ck
Klappan River
Chismore Ck
Tumeka Lk
Sweeny Ck
F
E
Nass River
Bell-Irving River
Konigus Ck
Alger Ck
C
D
45'
30'
15'
57°00'
130°00'
45'
30'
15'
129°00'

Figure 2. Generalized geological map of the study area, showing main stratigraphic units, facies in the Bowser Lake Group, axial surface traces of major folds, and location of cross-sections in Figure 6.

groups, and the Maitland volcanics. The Bowser Lake Group is divided into five units, of which four are not conventional rock-stratigraphic units. The fifth, the Ashman Formation, is a regionally mappable unit that is defined for the southern Bowser Basin (Tipper and Richards, 1976). The others are units grouped on the basis of common lithologies, sequences, sedimentary structures, and fossils. These characteristics reflect the general environment of deposition. Although they are presumed to evolve from marine to nonmarine in a general regression, there is no place where a complete section can be observed. Areas with good exposure of several hundred metres of section are separated by complex structures or by large, drift-covered valleys with unknown structure. As a result, the stratigraphic relationships of neighbouring areas are unknown, and the map of the Bowser Lake Group is a generalized facies map.

Hazelton Group

Lower and Middle Jurassic volcanic rock surrounding large parts of the Bowser Basin are called the Hazelton Group, a term redefined by Tipper and Richards (1976) for strata south and southeast of the Bowser Basin. In Spatsizi map area, volcanics of the Hazelton Group are referred to informally as the Cold Fish volcanics (Thomson et al., 1986; Evenchick, 1986) and comprise a subaerial to shallow-marine bimodal suite (Thorkelson, 1988). Most rocks are Early Pliensbachian (Early Jurassic) in age, but volcanics of Toarcian (late Early Jurassic) and Bajocian (early Middle Jurassic) age are also present (Smith et al., 1984).

In western Spatsizi map area the volcanics were examined where they are in contact with the Spatsizi Group (Fig. 2). Lithologies near the contact include basalt, rhyolite, tuff, breccia, volcanogenic sandstone, and conglomerate. These strata are included in the area mapped as Bajocian volcanics by Smith et al. (1984).

Spatsizi Group

The Spatsizi Group was established by Thomson et al. (1986) for marine clastic sedimentary rock in central Spatsizi map area that range in age from Early Jurassic to early Middle Jurassic. It is thought to be a basinal facies equivalent of the Hazelton Group (Smith et al. 1984; Thomson et al. 1986).

Reconnaissance mapping by Gabrielse and Tipper (1984) showed Bowser Lake Group north of Todagin Creek to be mainly in fault contact with volcanic rocks of the Hazelton Group. The local stratigraphic contact between the two units implied that the Spatsizi Group is absent. Mapping this season revealed a semi-continuous outcrop belt of Spatsizi Group between the underlying volcanics and the overlying Bowser Lake Group (Fig. 2). Contacts with underlying and overlying units are commonly covered by overburden; they are assumed to be stratigraphic because all map units are represented. The contact between the Spatsizi Group and Bowser Lake Group was seen in one locality. There, siltstone and chert-pebble conglomerate of the Bowser Lake Group are underlain by 3 m of fine and medium grained sandstone and, lower still, by siliceous, varicoloured siltstone of the Spatsizi Group. The siltstone is assigned to the Quock Formation of the Spatsizi Group because of strong lithological similarity. The apparent thickness of the Spatsizi Group ranges from about 40-100 m. Thrust faults and duplexes structurally thicken the section to account for the higher figure, which is far less than the maximum thickness of 730 m at the type locality in central Spatsizi map area. No minimum thickness was given by Thomson et al. (1986).

Bowser Lake Group

The Bowser Lake Group is divided into five lithological units (Fig. 2). These are described below in order of marine to nonmarine, with no stratigraphic order implied. The Ashman Formation has been mapped at the base of the Bowser Lake Group elsewhere (Tipper and Richards, 1976; Gabrielse and Tipper, 1984). The other four units are facies that probably overlap in time and may repeat in a vertical section.

Ashman Formation

The Ashman Formation is the lowest mappable unit of the Bowser Lake Group and overlies the Spatsizi Group at many localities in central Spatsizi map area (Gabrielse and Tipper, 1984). It consists of a thick section of black-weathering siltstone and very fine grained sandstone. Lenses and laterally continuous sheets of conglomerate are also present. The thick, dominantly dark, recessive-weathering, fine grained clastics, are assigned to the Ashman Formation on the basis of stratigraphic position above the Spatsizi Group and lithological similarity to Ashman Formation to the east (Gabrielse and Tipper, 1984; Evenchick, 1987). The section north of Todagin Creek directly overlies the Spatsizi Group and is at least 1400 m thick. Ashman Formation also occurs south of Todagin Creek on the lower flanks of Tsatia Mountain and the surrounding ridges. Thick sections of black siltstone with minor sandstone and conglomerate north and south of Chismore Creek are correlated with Ashman Formation (Fig. 2) on the basis of lithological similarity. Ashman Formation in central Spatsizi map area is Late Bathonian to Early Oxfordian in age (Gabrielse and Tipper, 1984), but the upper and lower age limits in the area studied are unknown.

Turbidites

The southwest corner of the map area is underlain by intervals 3-30 m thick dominated by recessive, black-weathering siltstone to very fine grained sandstone, and by resistant, grey weathering, fine to medium grained sandstone (Fig. 3). Sedimentary structures in the fine grained members are parallel lamination, graded bedding, and soft sediment folds. Sedimentary structures in the medium grained members are parallel lamination, massive beds, tool marks, and flute casts; beds vary from 1 cm to 2 m thick. Within each member, the proportion and thickness of beds of the less dominant lithology increases up, and in some intervals, decreases up.

The abundance of graded bedding, the common presence of sole marks on the bottom of massive, medium grained sandstone beds, and the monotonous, rhythmic repetition of

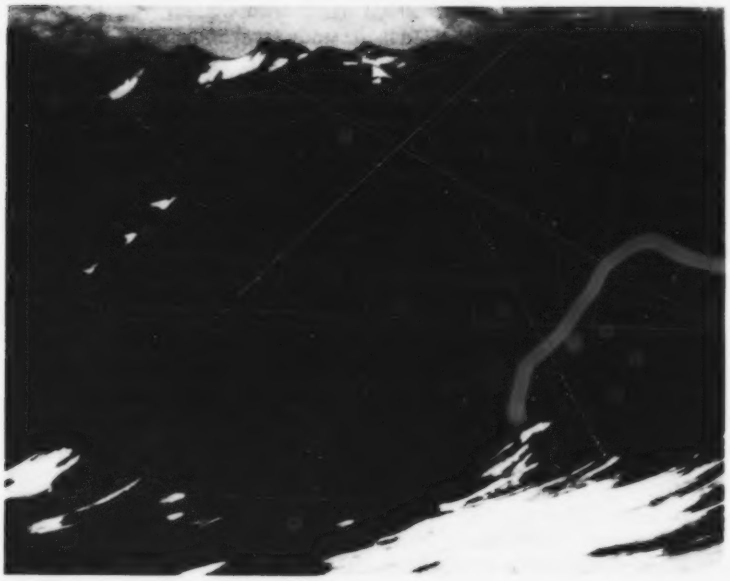


Figure 3. View east of turbidites west of Bell-Irving River. Note the repetition of large- and small-scale resistant sandstone (grey) and recessive siltstone (black) members.

siltstone and sandstone suggest that the rocks are turbidites (Walker, 1984) that were deposited in lobes on the mid and lower fan. The thinning and thickening-up sequences presumably reflect the migration of lobes.

West of Bell-Irving River, at least 1400 m of turbidites are overlain by more than 500 m of black siltstone with conglomerate lenses and sheets that are inferred to be channels feeding distal lobes. The change from turbidite to black siltstone with channels of conglomerate is interpreted to be the result of progradation of slope and inner fan facies above the distal mid and outer fan facies. The part of the section with lenses of conglomerate in thick black siltstone bears many similarities to the Ashman Formation, and is shown as Ashman Formation in Figure 2.

Shallow marine to nonmarine clastic rock (locally coal-bearing)

Most areas shown in Figure 2 as shallow-marine to nonmarine are isolated areas of unknown stratigraphic position relative to other areas. Only between Todagin Creek and the head of Tsatia Creek can this facies be related to other map units. This region needs more study.

On Tsatia Mountain the Ashman Formation is overlain by more than 300 m of fine and medium grained green sandstone with abundant marine fossils. Discrete lenses of conglomerate occur near the upper part the section. The section dominated by medium grained sandstone is overlain by at least 200 m of rusty-weathering chert-pebble to cobble conglomerate members 10-30 m thick, interbedded with thinner members of fine and medium grained dark sandstone, and rare sandy limestone. The dark intervals contain pelecypods and ammonites, attesting to marine deposition for at least part of the uppermost section. Details of the stratigraphy and sedimentology are given by Ricketts (1990).

A wide range in bed thickness and in the proportion of fine grained clastic sediment to coarse grained clastic sediment characterizes the areas south of Tsatia Creek, north and south of Maitland Creek, and east of Klappan River. Typical sections include: 10-30 m thick coarsening-up cycles with coal and/or carbonaceous siltstone at the base and chert-pebble conglomerate at the top, similar sections with less conspicuous cycles, less conglomerate and no coal, and thick sections of fine and medium grained sandstone (with massive bedding or parallel lamination) and rare coal.

Local coal seams indicate a nonmarine environment. The overlying and underlying strata, however, contain pelecypod coquinas and, less commonly, ammonites, indicating fluctuations between marine and nonmarine conditions.

Nonmarine clastic rock

At least 500 m of section east of Sweeny Creek is dominated by sequences that fine upward from conglomerate (not everywhere present), through massive sandstone, platy sandstone with interbeds of siltstone, thin bedded sandstone and siltstone, dark green sandstone and siltstone, into carbonaceous siltstone with abundant plants and locally coal. The fining up sequences, abundance of delicate plant fossils, and absence of marine fossils suggest a nonmarine, fluvial environment.

Maitland volcanics

The Maitland volcanics are a suite of Early Pliocene flat-lying basalt flows that occur as erosional remnants on the tops of plateaus and peaks between Tsatia Creek and Chismore Creek (Fig. 2, 4; Souther, in press). The remnants consist of laterally continuous sheets of columnar basalt 3-30 m thick. The maximum thickness of a section of flows is 350 m. The upper erosion surface of the flows forms a plateau at 1960-2260 m (6500-7500 ft) elevation. The lower surface of the flows follows a pre-Pliocene peneplain at 1960-2110 m (6500-7000 ft) on the west, dropping to as low as 1510 m (5000 ft) and lower at the northeast-most occurrences shown in Figure 2. Relief on the lower contact of the flows is minor in most places, but locally is as much as 300 m in 2 km. (Fig. 8). Basalt necks, which rise as much as 200 m above the surrounding topography (Fig. 4), are assumed to be the feeders; they are 100-400 m across the long axis of their oval or circular plan. Fourteen feeders are clustered in a small area northwest of Maitland Creek.

Discussion of stratigraphy

Although little fossil control is available, some generalizations about the stratigraphy of the Bowser Lake Group can be drawn from local relationships. In the north, the Spatsizi Group is overlain by about 1400 m of Ashman Formation, which is in turn overlain by more than 500 m of shallower marine to nonmarine strata. On Tsatia Mountain, the first strata with abundant coal above the Ashman Formation are probably within 500 m of the top of the section on Tsatia Mountain, or in part overlap it. In the south, typical Ashman Formation overlies turbidites at least 1400 m thick that are absent in the north. The combined thickness of turbidites and Ashman Formation is 1900 m, and probably much greater, because the thickness of strata between these beds and the base of the Bowser Lake Group is unknown, as is the thickness between the top of these beds and the first shallow marine or coal-bearing strata. Although estimates of thickness are approximate, the thickness of turbidites and Ashman Formation in the south is probably greater than the thickness of Ashman Formation and overlying strata to the first coal-bearing beds in the north. Biostratigraphic control is needed to refine the stratigraphic position of all units, including the nonmarine strata east of Sweeny Creek, that could be either younger, older, or the same age as shallow marine strata to the west and northwest.

The units described by Cookenboo and Bustin (1989) were not recognized in the study area. Some sections in west Spatsizi area probably represent similar depositional environments to the units outlined by Cookenboo and Bustin (1989), but their stratigraphic position is unknown. As in areas to the east, intense folding and poor biostratigraphic control inhibit recognition of a truly regional stratigraphy.

STRUCTURAL STYLE

The style and orientation of folds on the west side of Spatsizi map area are diverse. Some complexities of the structure are described here. Figure 5 is a summary of stereonets for the regions studied. Each net is centred on the area it represents, and the diameter is roughly the across-strike distance of the area. Regions of relatively simple, cylindrical folding are illustrated by stereonets in which poles to bedding define a great-circle girdle. Areas of more complicated folding, resulting from either superposed folding or noncylindrical folding, are illustrated by a less systematic spread of poles to bedding. Three regions of 'simple' folding, each with a different style and orientation surround a central area of complex folding. In the north, strata are gently folded about northeast and northwest trending axes; northeast axes predominate and the plunge is gentle (Fig. 6, section AB). In the south, between Alger Creek and BellIrving River, strata are also folded about northeast-trending, gently plunging axes. In contrast to structures in the north, these are open to tight folds which have accommodated more than 40 % shortening (Fig. 6, section CD). East of Alger Creek folds verge to the east, and west of Bell-Irving River they verge to the northwest. The change in vergence suggests a structural culmination between the two areas. East and west of Sweeny Creek and north of Nass River, northwest axial surface trends so common in the rest of Spatsizi map area (Evenchick, 1988, 1989) dominate. East of Sweeny Creek, folds are upright or northeast-verging, and open to close (Fig. 6, section EF). West of Sweeny Creek they are large scale, upright or southwest-verging chevron folds (Fig. 7).

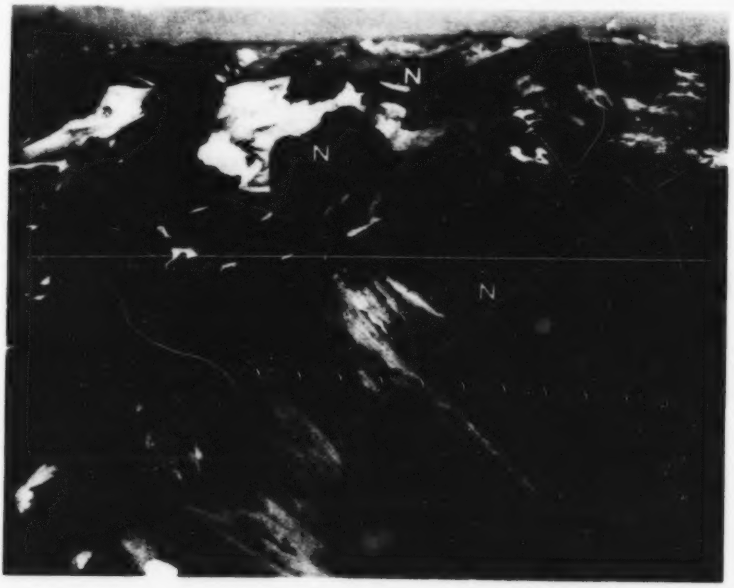
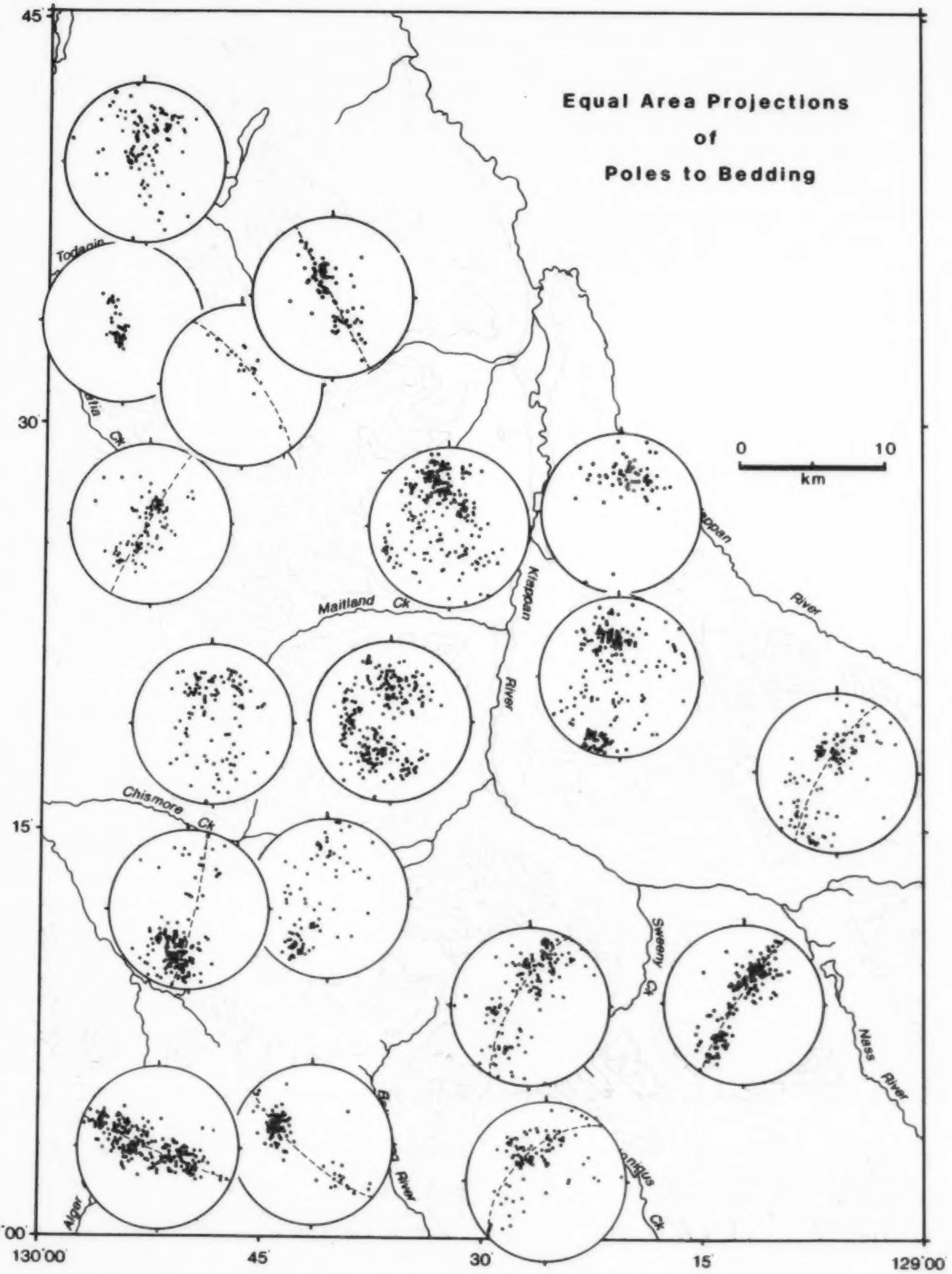


Figure 4. View east to flows and necks of the Maitland volcanics west of Maitland Creek. Three necks are marked by the letter 'N'. The ridge between the two closest necks is capped by flows of columnar basalt.



Equal Area Projections
of
Poles to Bedding
0
10
km
45'
30'
15'
57°00'
130°00'
45'
30'
15'
129°00'
Todagin
Ck
Maitland Ck
Klappan River
River
Chismore Ck
Sweeny Ck
Nass River
Alger
River
Ck

Figure 5. Map of study area with lower hemisphere, equal area projections of poles to bedding. Note the contrast of regions with poles to bedding falling on or near great circles. Regions in the centre of the map have an unsystematic scatter of poles to bedding.

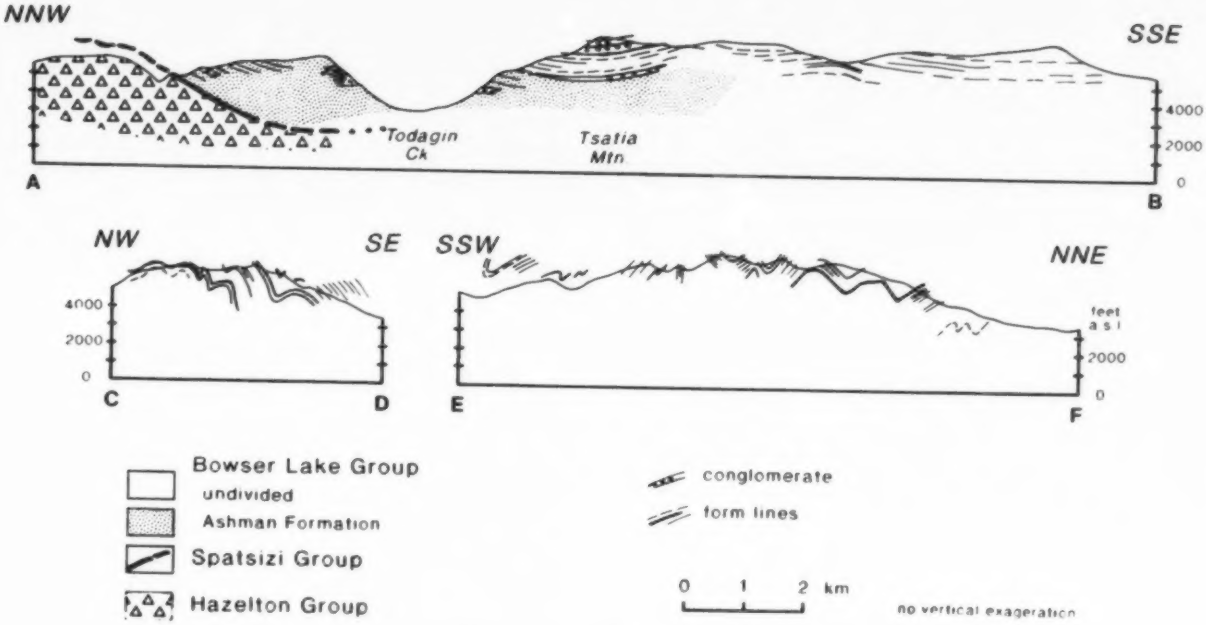

NNW
SSE
Todagin Ck
Tsatia Mtn
A
B
4000
2000
0
NW
SE
SSW
NNE
C
D
E
F
feet a.s.l.
Bowser Lake Group
undivided
Ashman Formation
Spatsizi Group
Hazelton Group
conglomerate
form lines
0 1 2 km
no vertical exageration

Figure 6. Representative structural cross-sections of three areas of roughly cylindrical folding. Location of the sections shown in Figure 2.

Figure 7. View southeast to large scale chevron folds west of Sweeny Creek.

The regions of differently oriented, but relatively simple folds surround an area (middle of Fig. 5) of complex fold patterns resulting in a wide scatter of poles to bedding, on the scale of this analysis. Closer examination of one area (Fig. 8) illustrates that it can be broken into three domains of cylindrical folding, but one net remains as a scatter of poles in this more detailed analysis. In this example the domains consist of small-scale tight folds that are cylindrical within the domain, but the trend and plunge vary between domains. It is not clear that the different fold trends interfere with each other; large-scale noncylindrical folding may be the cause of the different fold orientations. In many areas of open to close folding, interference of folds can be observed in the field. For these areas it is clear that a poorly defined great circle is caused by the interference of folds. The relative tightness of the two fold trends determines whether poles fall on a poorly defined great circle, or are too scattered to define a great circle. No consistent pattern of overprinting of folds was observed.

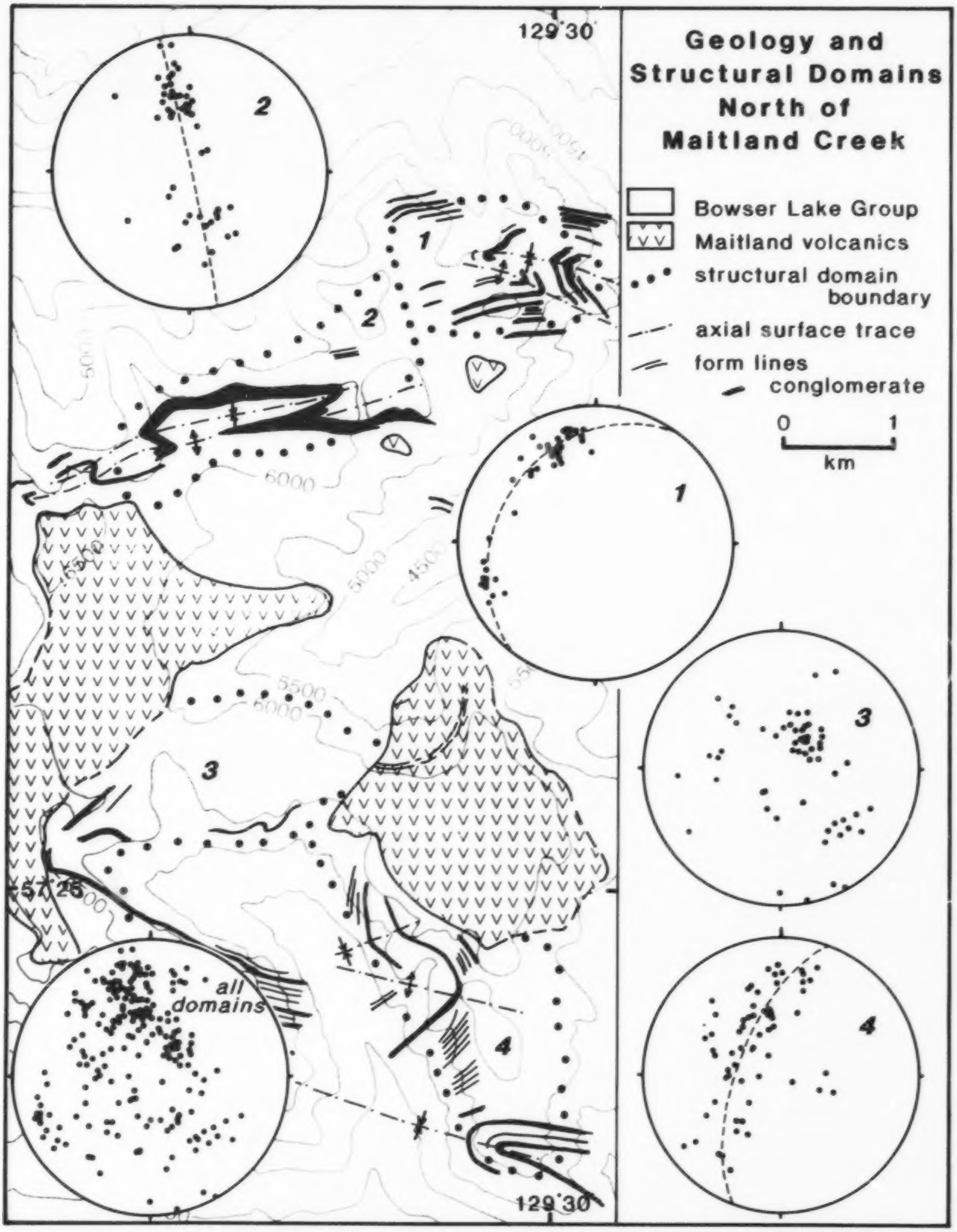

129°30'
Geology and Structural Domains North of Maitland Creek
Bowser Lake Group
Maitland volcanics
structural domain boundary
axial surface trace
form lines
conglomerate
0
1
km
1
2
3
4
all domains
57°25'
5000
5500
6000
4500
129°30'

Figure 8. Map of Maitland volcanics and structural domains in the Bowser Lake Group north of Maitland Creek. In this region the lower contact of the Maitland volcanics follows irregular pre-Pliocene topography through more than 300 m of relief, in contrast to areas to the west where it follows a peneplain. The stereonets of poles to bedding in the Bowser Lake Group illustrate how a region of apparently complicated folding, shown by the stereonet of all domains, can be divided into domains of roughly cylindrical folding.

The shape and tightness of folds vary across the area. Gentle large scale folds in the northwest, near the contact with the Hazelton Group, contrast with most of the rest of the study area where folds are generally smaller scale, close or tight (compare sections in Fig. 6). Thrust faults are present, but the lack of markers prohibits estimates of stratigraphic throw.

Summary of structural style

Axial surfaces of folds in west Spatsizi map area range in trend from northeast, north-northeast, northwest, west-northwest, and west. The variety in trends contrasts with the consistent northwest trends of folds in central and east Spatsizi map area (Evenchick, 1988, 1989). In some areas the different trends interfere or are noncylindrical, producing complicated fold patterns, but other areas are dominated by only one trend of folds.

Stratigraphic relationships in west Spatsizi map area provide few constraints on the timing of deformation. Folds must be younger than the youngest Bowser Lake Group, which is Late Jurassic in this region, and older than the Maitland volcanics, which are Early Pliocene.

ACKNOWLEDGMENTS

We acknowledge the fine assistance in the field by Kirsten Nicholson (University of British columbia) and David Sarkany (Capilano College). Once again, the cooperation of Mike Jones of Tatogga Lake Resort was helpful in many aspects of base camp operations. The cooperation and support of Brian McCarthy of Canadian Helicopters Inc. added substantially to the success of the fieldwork.

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A preliminary account of sedimentation in the lower Bowser Lake Group, northern British Columbia[1]

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Ricketts, B.D., A preliminary account of sedimentation in the lower Bowser Lake Group, northern British Columbia; in Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 145-150, 1990.

Abstract

Preliminary investigation of the lower part of the Bowser Lake Group in Spatsizi and eastern Telegraph Creek map areas indicates a continuum of lithofacies ranging from relatively deep submarine fans, prodelta-slope with many incised submarine gullies and canyons, fan deltas, and interfan shelves. The succession ranges in age from late Bathonian or Callovian to possible Oxfordian. The transition from the fan delta-shelf facies assemblages to the prodelta-slope assemblage appears to pass through a depositional hinge. The submarine gullies and canyons, some more than 200 m thick, permitted coarse sediment to bypass the slope region and fed coarse grained submarine fans. Abrupt vertical and lateral facies changes indicate a dynamic depositional realm wherein sediment supply rates and routes changed frequently, probably in response to active tectonism in the sediment source terrain and rapid basin subsidence.

Résumé

L'étude préliminaire de la partie inférieure du groupe de Bowser Lake dans les régions des cartes de Spatsizi et de Telegraph Creek est indiquent un continuum de lithofaciès allant de cônes sous-marins relativement profonds, en passant par des talus avec de nombreux ravinements des cônes de déjection et canyons sous-marins, à des plates-formes intercônes. L'âge de la série varie du Bathonien supérieur ou Callovien à probablement l'Oxfordien. La transition des ensembles de faciès de cônes de déjection – plate-forme à l'ensemble de prodelta-talus semble passer par une charnière de sédimentation. Les ravinements et les canyons sous-marins, dont quelques-uns dépassent 200 mètres d'épaisseur, ont permis aux sédiments grossiers de contourner la région du talus pour alimenter des cônes sous-marins à grain grossier. D'abrupts changements de faciès verticaux et latéraux indiquent un lieu de sédimentation dynamique où les vitesses d'apport des sédiments et les routes changeaient fréquemment, probablement à la suite d'une tectonique active dans les terrains d'origine des sédiments et de la subsidence rapide des bassins.

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[1] Contribution to Frontier Geoscience Program

INTRODUCTION

The Middle to Upper Jurassic Bowser Lake Group, which underlies an enormous tract of northern Intermontane British Columbia, affords an excellent opportunity to examine gravel-dominated depositional regimes that range from nonmarine to relatively deep marine basins. Huge volumes of chert-dominated conglomerate, shed generally southwards, supposedly were derived from a northern component of the accretionary Cache Creek Terrane (e.g. Eisbacher, 1981). Preliminary investigations in the northern part of Bowser Basin (Spatsizi and Telegraph Creek map areas, Fig. 1) indicate that coarse sediment accumulated in fan deltas, with some dispersal over narrow, interfan shelves. However, large volumes of gravel and sand also bypassed the shelves, being funnelled down submarine canyons and gullies that were eroded into muddy prodelta-slope strata. The logical, basinward extensions of these sediment conduits, namely depositional systems indicative of proximal (conglomerate-dominated) and medial or distal (sand-mud dominated) submarine fans have also been found.

Each of these depositional realms contains a variety of lithofacies, herein grouped into broad facies assemblages: fan delta, shelf, prodelta-slope, and submarine fan. Possible alluvial equivalents of the fan deltas have been examined only briefly in strata of probable Oxfordian age.

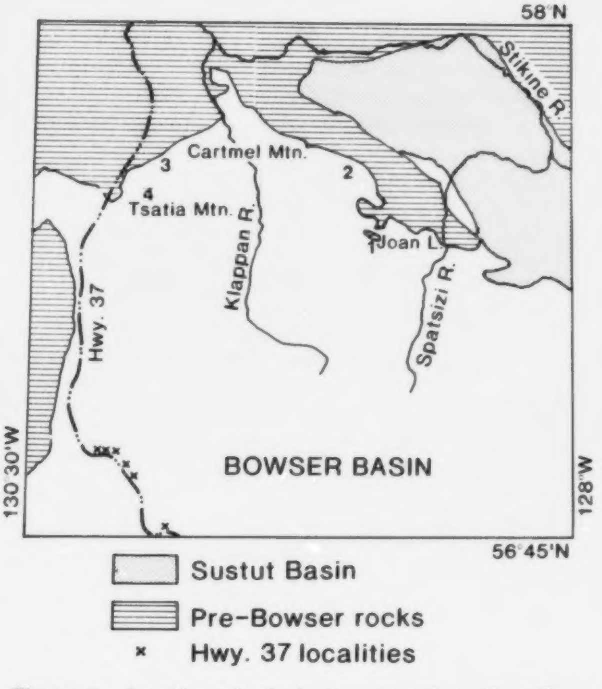
58°N
Stikine R.
Cartmel Mtn.
3
2
4
Tsatia Mtn.
Klappan R.
Joan L.
Spatsizi R.
Hwy. 37
BOWSER BASIN
130°30'W
128°W
56°45'N
Sustut Basin
Pre-Bowser rocks
× Hwy. 37 localities

Figure 1. Location of principal measured sections illustrated in Figure 2. 1 = Joan Lake area, RAK 2,3,6 -89; 2 = Iceberg Canyon, RAK 7,9 -89; 4 = Todagin Mountain, RAK 11-89; 4 = Tsatia Mountain, RAK 14-89. Outcrops of turbiditic facies along Highway 37 are marked by crosses. The area covered includes Spatsizi map area, and parts of Telegraph Creek, Iskut and Bowser map areas.

The facies outlined in this report occur in the upper Bathonian to Oxfordian Ashman Formation of the Bowser Lake Group (Duffell and Souther, 1964; Tipper and Richards, 1976; Thompson et al., 1986). The Ashman Formation has traditionally been defined as a succession of dark grey siltstone and shale with thin, buff-weathering fine sandstone and conglomerate interbeds. Ashman strata in the Spatsizi and Telegraph Creek map areas contain significant quantities of conglomerate and coarser sandstone in sediment bodies of highly variable lateral and vertical extent. Although the Ashman succession overall has a recognizably coarsening upwards aspect, there is a great deal of lateral and vertical lithological variability which, in concert with complex structural deformation over most of the basin (Evenchick, 1988), creates major problems for correlation of stratigraphic sections. The degree to which this problem can be overcome will depend to a large extent on establishing a sound biostratigraphic framework. Current macropaleontological studies by T.P. Poulton (GSC) and R. Hall (University of Calgary) will augment existing palynological zonal schemes (e.g., Moffat et al., 1988; Cookenboo and Bustin, 1989). Thus, correlation of the measured sections shown in Figure 2 is necessarily preliminary.

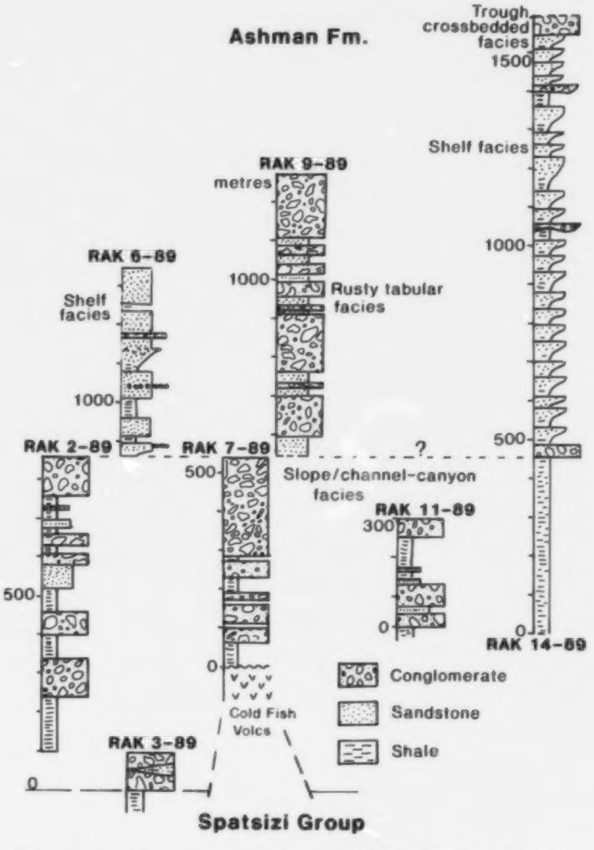
Ashman Fm.
Trough crossbedded facies
1500
Shelf facies
1000
500
0
RAK 14-89
RAK 9-89
metres
1000
Rusty tabular facies
RAK 6-89
Shelf facies
1000
RAK 2-89
RAK 7-89
500
?
Slope/channel-canyon facies
RAK 11-89
300
0
500
0
Conglomerate
Sandstone
Shale
Cold Fish Volcs
RAK 3-89
0
Spatsizi Group

Figure 2. Measured sections, and broad facies designations through the lower Bowser Lake Group are shown schematically (and highly simplified). Section locations are indicated in Figure 1.

SUBMARINE FAN ASSEMBLAGE

Sandy turbidite facies

Tabular bedded, graded sandstones up to 3 m thick, and in places arranged in bed-thickening upwards successions, were observed in roadcuts between Barrage River and Bell II station (Fig. 1). Although the base of the Ashman Formation has not been found in this transect, it seems likely that the sandy turbidite facies is close to this contact, based on regional structural considerations. If so, then the facies is the lateral equivalent of the tabular conglomerate facies described below.

Thin bedded turbidites contain mostly Tb to Td (or the pelitic Te) Bouma divisions. More massive sandstone beds higher in the upwards-thickening successions are commonly composite, composed of two or three stacked and graded beds having Bouma Ta-Tb divisions and separated by a layer of shale rip-up clasts. Flame structures, flute and groove casts are common, and generally indicate south to southwest flow directions. At two localities, thickening upwards packages are capped by pebbly mudstone units up to 2 m thick; each thickening upwards package is about 50 m thick. A few ammonite, *Buchia* and *Astarte* fragments have been found. Trace fossils also are scarce; those recognized include *Planolites*, and possible *Gyrochorte* or *Didymaulichnus*.

Tabular conglomerate facies

A unit of conglomerate, in places more than 100 m thick, represents the lowest Bowser Lake Group at localities where contact with the underlying Spatsizi Group is exposed (e.g. Joan Lake area, Fig. 1). The unit can be traced laterally over several kilometres and has a tabular, sheet-like geometry, with local pinching and swelling. The geometric disposition of this facies is distinct from the lenticular (channelized) conglomerate facies found higher in the succession (Fig. 3). Internally the conglomerate unit is highly complex, consisting of stacked, conglomerate wedges, up to 50 m thick and tens to hundreds of metres wide. The conglomerate wedges in turn interfinger with wedges of interbedded sandstone and shale. Contacts between wedges are abrupt; coarsening or fining upwards stratigraphic patterns are rare.

The conglomerate wedges themselves are made up of smaller scale wedge sets, sometimes arranged into large, gently dipping (10-12°) foresets up to 15 m thick. Individual conglomerate foresets are capped by sandstone beds that pinch out up foreset dip. No smaller scale crossbedding has been observed.

Conglomerate frameworks range from clast-supported with pronounced pebble alignment (some imbrication), through a spectrum of fabrics that, at the opposite extreme, includes pebbly mudstone. Some beds contain inverse grading in their lower few centimetres; normal grading is less common. Associated sandstone wedges (up to a metre thick) also are nongraded, commonly parallel laminated; as with the conglomerates, no small scale crossbedding has been observed.

Interbedded turbiditic sandstone and shale compose relatively recessive wedge-shaped sediment bodies that interfinger with the conglomerates. Sandstone beds less than 40 cm thick are generally fine grained, having Tb to Td Bouma divisions. The rippled Tc divisions rarely contain convoluted laminae. These turbidites are arranged into both bed thickening- and bed thinning-upwards packages 2-4 m thick. Graded turbidites only a few centimetres thick typically contain numerous starved ripples that impart a pinch and swell character to the beds. Less common are beds of pebbly mudstone in which the mud matrix comprises 20-30%.

PRODELTA-SLOPE ASSEMBLAGE

Shale facies

Thin, interbedded siltstone and shale compose much of the Ashman Formation. Both normally graded and nongraded beds a few millimetres to 20 cm thick occur. Delicate laminae are well preserved, bioturbation being uncommon and attesting to low levels of faunal activity. Ripples, including starved varieties also occur. More common, especially in graded beds (commonly Tb/Td or Tc/Td divisions), are indications of soft sediment deformation. These include pull-apart (boudinage) structures, detached load structures, convoluted laminae, and microfaults that extend through only a few centimetres of sediment. The soft sediment faults impart a wispy texture to the mudrocks — a characteristic feature of Ashman shales.

On a larger scale, low angle discordances are common and demarked by rapid thinning of sandstone beds, or sandstone filling of shallow channel structures generally less than a metre or two thick. The discordances are in some places associated with large scale slump packages (see below).

Slump facies

Soft sediment slumping is common in the Ashman mudrocks and may involve upwards of 50 m of stratigraphy. At Joan Lake a major slump package can be traced laterally for several kilometres (Fig. 1 and 3). Slump structures range in size from small folds of one or two metres amplitude, to large blocks of displaced, overturned and internally disrupted conglomerate 40 m thick. As expected, shales beneath the displaced blocks also exhibit considerable disruption; overlying deposits contain depositional discordances. Sandstone dykes are common in the slump packages. Notably, channel structures in the shale facies commonly are spatially associated with slump-generated discordances.

Lenticular conglomerate (channel) facies

An outstanding component of the shale lithofacies assemblage is lenticular conglomerate bodies ranging in thickness from a metre to more than 200 m thick, and from a few metres to perhaps 10 km wide (Fig. 3). In all cases examined, the channel-like conglomerates are encased in mudrocks; have abrupt top, base and marginal contacts; and are not associated with coarsening or fining upwards stratal trends. Basal contacts clearly are erosional with up to 5 m relief; some upper contacts also exhibit erosional discordances even though they are overlain by shaly lithologies. Channel margins range in orientation from gradual pin-

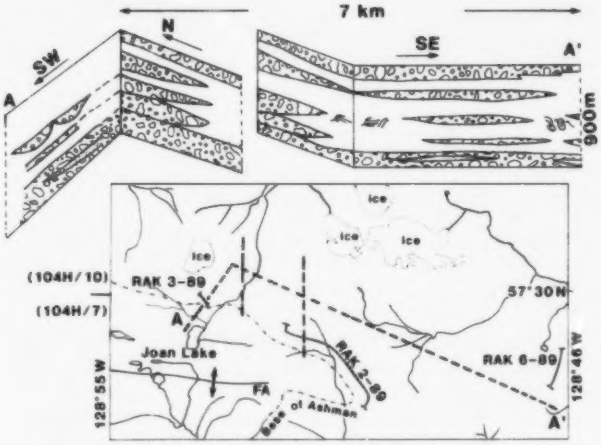

Figure 3. This fence diagram illustrates the three dimensional geometry of the tabular conglomerate facies (basal unit) and lenticular conglomerate facies in the Ashman Formation, Joan Lake area. Note the amalgamation of conglomerates into a thick (more than 200 m) unit in the northwest corner of the diagram, and the package of slumped beds that can be traced laterally for several kilometres within the intervening shale facies.

chouts to abrupt, subvertical walls 20-30 m high. Individual conglomerate bodies may also amalgamate into very thick units.

The internal organization of the lenticular conglomerate facies is complex (Fig. 4), but similar to the tabular conglomerate facies, with the exceptions that large conglomerate foreset are more common, and the thick, recessive (turbiditic) sandstone-shale wedges less common. Many of the large foresets have tangential toesets.

SHELF ASSEMBLAGE

Coarsening upwards sandstone facies

This facies is transitional, over a few metres, from strata of the prodelta-slope assemblage and ranges in thickness from 500 m (Joan Lake area) up to 1000 m (Mount Tsatia, Fig. 1 and 2). It also appears to be laterally equivalent, at least in part, to the tabular, rusty conglomerate facies (fan delta assemblage).

The facies is characterized by many stacked, coarsening and bed-thickening upwards units (cycles) up to 22 m thick. Each unit in turn contains several smaller scale coarsening upwards cycles. A few thin turbidites occur in the lower shaly components. Sandstone beds increase in thickness upwards, and in a few units pass into thin conglomerate beds or pebbly sandstone. Other stratigraphic trends within each cycle include an increase in the proportion of low-angle planar crossbeds and hummocky cross-stratification. Scour pockets filled with mud rip-up clasts interfinger with a few hummocky cross-stratified beds. Some trough crossbedding occurs in sandstones near the top of the facies successions, near the transition into the trough crossbedded conglomerate facies.

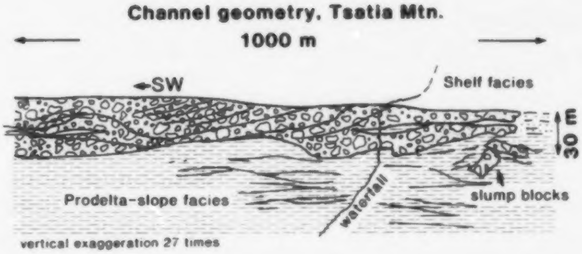

Figure 4. This field sketch illustrates the complex internal organization of the lenticular conglomerate facies at Mount Tsatia. Channel fill occurred in several stages, as indicated by the numerous lenses and veneers of mudrock, some containing thin, fine grained turbidites, and the complex association of large, shallow-dipping foresets with channel scour bases. Channel fill was characterized by lateral migration of thalwegs and vertical stacking of depositional units.

A greater diversity of trace fossils occurs in this facies than has been observed in any of the other facies; ichnogenera include *Planolites*, *Chondrites*, *Thalassinoides*, *Skolithos*, *Rosellia* (or *Asterosoma)*, and possibly *Rhizocorallium* or *Zoophycus*.

Many of the cycles are capped by conglomerate beds that have a different character to conglomerate and pebbly sandstone associated more intimately with the coarsening upwards trends. These capping conglomerates are identified primarily by their poor sorting, abrupt bases, tops that grade into shale of the overlying unit, frameworks that become increasingly mud-matrix supported towards bed tops, generally abundant fossils, and the absence of bedforms. Fossils commonly include brachiopods, gastropods, ammonites, belemnites and bivalves, with the mud-dwelling *Pina* sometimes in growth position. Particularly fossiliferous examples of these conglomerates were found in the lower part of the shelf assemblage at Mount Tsatia (Fig. 2) which contains an abundance of the lower to middle Callovian ammonite *Cadoceras* (T. Poulton, R. Hall, personal communication, 1989).

FAN DELTA ASSEMBLAGE

Tabular, rusty conglomerate facies

Distinctly rusty weathering conglomerates in tabular, sheet-like units occur in successions at least 700 m thick in the Joan Lake-Mount Cartmel area (Fig. 2). They overlie strata of the prodelta-slope assemblage and are laterally equivalent to shelf assemblage facies. The facies also grades into the trough crossbedded conglomerate facies.

Individual conglomerate units range in thickness up to 20 m, and can be traced laterally for up to 8 km and more. At Icebox Canyon (Fig. 1) more than 30 such units occur within a 700 m thick succession. Most have abrupt tops, and bases that grade upwards from the intervening sandstone-shale intervals. Internally, the conglomerates consist of tabular and wedge shaped beds, and some foresets up to 10 m thick with angular discordances of 8-10°. Foreset layers are nongraded, either normal to bedding or up foreset dip. Sandstone wedges pinchout up-dip. Sandstones are parallel laminated and less commonly, trough crossbedded or rippled. Gravel ripples are relatively common, having amplitudes of 20 cm and wave lengths of about a metre.

Conglomerate frameworks include a broad spectrum of clast and matrix supported fabrics, similar to conglomerates in the prodelta-slope and submarine fan assemblages. In some cases, clast supported, laminate pebble conglomerates with pronounced clast alignment can be traced laterally within single depositional units into pebbly mudstone; one example has been observed in a thick foreset package (more than 100 m thick) near Mount Cartmel.

Stratigraphic trends throughout the rusty, tabular facies include:

— shallow channelling in the lowest conglomerate units becoming less common higher in the succession;

— thin, turbiditic sandstones in the recessive intervals generally are confined to lower stratigraphic intervals; higher in the succession the sandstones contain some trough crossbedding;

— the proportion of poorly sorted, clast and matrix supported fabrics decreases upwards, being replaced by better sorted clast supported frameworks, in concert with an increase in the abundance of crossbedding;

— the proportion of recessive lithologies decreases upwards;

— maximum clast size increase upwards, up to 16 cm across;

— the proportion and size of plant debris increase upwards.

Trough crossbedded conglomerate facies

Trough crossbedded, rusty-weathering pebble and cobble conglomerate is the youngest lithofacies at Mount Tsatia, where it gradationally overlies coarsening upwards sandstone-shale units of the shelf assemblage (Fig. 2). Ammonites within the associated shelf facies include the uppermost Callovian genus *Quenstedtoceras* (T. Poulton, personal communication, 1989). In the Mount Cartmel area the facies appears to be in gradational contact with subjacent tabular, rusty conglomerates. Festooned trough crossbeds up to 2 m thick contain abundant wood. Carbonaceous shale was seen at one locality east of Mount Tsatia but was not examined in detail. Sandstone lenses also contain trough crossbeds, some planar tabular crossbeds and parallel laminae. Conglomerate frameworks are all clast-supported and hence contrast the highly variable framework types found in the other conglomerate facies.

INTERPRETATION OF FACIES

The sandy turbidite facies constitutes the sandy component of a series of south to southwest prograding submarine fan lobes, and compares favourably with Facies B of Mutti and Ricci Lucchi (1978). It is the most basinward component of the submarine fan assemblage seen to date, although the low proportion of muddy lithologies and turbidite beds of distal character (e.g., compared to Facies D of Mutti and Ricci Lucchi, 1978), suggests a position well up on the fans, still within reach of cohesive, muddy debris flows. The tabular conglomerate facies, exposed farther north, is tentatively assigned to a more proximal position on the submarine fans, perhaps at the toe-of-slope where submarine channels or canyons fed coarse sediment to the principal channels of adjacent fans. The locus of gravel transport within the proximal fan channels was constantly shifting, as evidenced by the complex array of conglomerate wedges that interfinger with the thin, fine grained turbidite-shale wedges. The latter have the characteristics of channel overbank deposits (e.g. Facies E of Mutti and Ricci Lucchi, 1978). Large foreset conglomerate units may be analogous to point bar deposits in high sinuosity alluvial channels, reflecting migration of channel thalwegs, although actual modes of deposition were quite different. Most conglomerates have the characteristics of debris flows with the range of conglomerate fabrics indicating that sedimentation processes also were quite variable. Debris flow mechanisms ranged from noncohesive, highly sheared flows (rapid flow), to cohesive, slow moving mud plugs. Changing flow mechanisms can even be demonstrated within single depositional units, where pebbly mudstones form the distal, slower moving portions of flows.

Aspects of the shale facies are typical of slope settings wherein sedimentation rates were relatively low (compared to the adjacent submarine fans), and where most sediment of medium sand size and greater was bypassed through an extensive system of channels, gullies and in some cases, steep-walled submarine canyons. The abundance of both large- and small-scale soft-sediment deformation structures in the shales attests to an unstable seafloor, consistent with higher depositional slopes than the adjacent basin floor and shelf. Sediment was probably derived from pelagic and hemipelagic sources, in addition to overbanking of the incised channels. All gullies and canyons observed so far are eroded into shale facies. Deposition within these channels was often episodic; like the submarine fan channels, the locus of sediment transport and deposition seems also to have frequently migrated. Channels were usually abandoned suddenly as indicated by abrupt tops. The spatial association of slump discordances in the mudrocks and many channel structures further suggests a possible causal relationship, where sediment was directed through slump-enhanced topographic depressions on the sea floor. The abrupt, commonly eroded terminations of these sediment conduits may also have been the result of slope failure (an idea suggested by T. Poulton). Abrupt changes in sediment supply to the channels may also have played a role.

The transition from the slope facies to the tabular, rusty conglomerate and coarsening upwards sandstone facies is everywhere gradational, but abrupt. This may indicate some kind of depositional hinge between the shallower (shelf and fan delta) and deeper (submarine fan) parts of the basin. All criteria characterizing the coarsening upwards sandstone facies indicate an actively aggrading and prograding shelf environment that frequently was subjected to storms. Each cycle of shelf deposition was terminated by a transgressive event that left its mark as poorly sorted, fossiliferous conglomerate caps, or lags; these transgressive lags are distinct from conglomerate beds that form part of the coarsening upwards trends in some cycles (perhaps reflecting proximity to shoreface). The transition from the conglomerate lags to mudrocks of succeeding cycles approximates the position of maximum flooding during each transgression.

Rusty, tabular conglomerates that are laterally equivalent to the shelf facies are interpreted as the distal parts of fan deltas. Deposition on the deeper portions of the fans was primarily by sediment gravity flow; presumably these flows also fed sediment into the submarine gullies and canyons. Some sediment was dispersed by traction currents (sand and gravel ripples); the proportion of bed-load transportation seems to have increased in the shallower, shoreward parts of the fans with probable shoreface components also preserved (trough crossbedded facies).

A PRELIMINARY VIEW OF THE REGIONAL PICTURE

The overall setting on the lower Bowser Lake Group (principally Ashman Formation, in the Spatsizi and eastern Telegraph Creek map areas, can be viewed as a complex of fan deltas and interfan shelves, that fed coarse sediment through prodelta-slope gullies and canyons onto submarine fans (Fig. 5). Preliminary paleocurrent analysis indicates that sediment transport was towards the south and southwest (confirming suggestions by Tipper and Richards, 1976 and Eisbacher, 1981). The lateral extent of the fan deltas is not yet known. It is clear, however, that this was an extremely dynamic system. Thick, stacked fan delta deposits, and the abrupt appearance and termination of submarine channels in the adjacent slope attest to rapidly changing sediment supply and abrupt lateral shifts at points where sediment was introduced into the basin. Such changes ultimately are related to changing base levels in the sediment source area. Given the thickness of the succession overall, the huge volumes of very coarse sediment even in the deeper parts of the basin, and the brief period of sediment accumulation, the most reasonable control on basin architecture was probably tectonic — that is rapid basin subsidence coupled with rapid uplift and erosion of the (northern) source terrain.

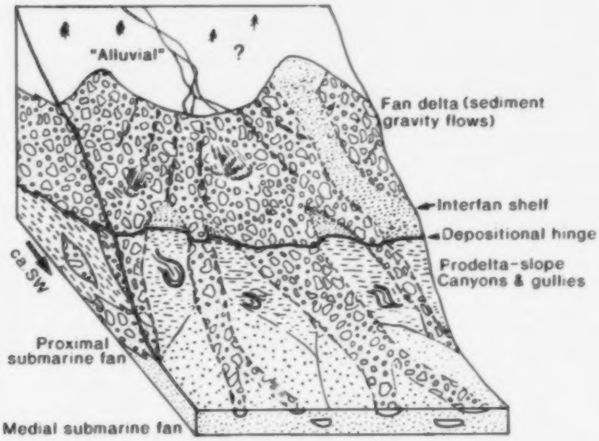

Figure 5. A hypothetical reconstruction of the paleoenvironmental setting for lower Bowser Lake Group strata in the Spatsizi and eastern Telegraph Creek map areas. The stratigraphic package represents a prograding complex of fan deltas and laterally associated shelves, slope, submarine channels and submarine fans. Depositional hinge refers to a marked geomorphic boundary at the shelf/fan delta-slope break, that is inferred from abrupt facies transitions. The "alluvial" component of the hypothesis has yet to be examined in detail.

ACKNOWLEDGMENTS

Carol Evenchick introduced me to Bowser Basin geology, with all its vagaries and foibles; Terry Poulton (ISPG), Russell Hall (University of Calgary), and John Callomon (University of London) led me through some of the intricacies of the biostratigraphy, and Shawna Vossler assisted in the field. All of these people are thanked.

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Lithostratigraphy of the northern Skeena Mountains, British Columbia[1]

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Cookenboo, H.O. and Bustin, R.M., Lithostratigraphy of the northern Skeena Mountains, British Columbia; in Current Research, Part F, Geological Survey of Canada, Paper 90-1F, p. 151-156, 1990.

Abstract

The two main coal-bearing units in the Groundhog and Klappan coalfields, the Currier and McEvoy formations, were previously unknown outside of the coalfields. The Currier Formation is now known to occur at least 25 km northwest of the Klappan coalfield and 5 km east of the Groundhog coalfield. The McEvoy Formation probably extends at least 15 km west of the Klappan coalfield. Facies changes within the Currier and McEvoy formations, including significant coal occurrences, are consistent with lateral variation in depositional systems. Strata assigned to the Ashman (Middle Jurassic) and Tango Creek (Upper Cretaceous) formations were also found in the area surrounding the coalfields. Facies of the Ashman Formation are marine and are the oldest rocks known from the study area. In contrast, facies of the Tango Creek Formation are typical of alluvial fan deposits, and probably are the youngest strata in the area.

Résumé

Les deux principales unités carbonifères des bassins houillers de Groundhog et de Klappan, les formations de Currier et de McEvoy, étaient auparavant inconnues à l'extérieur des bassins houillers. On sait maintenant que la formation de Currier est présente à au moins 25 km au nord-ouest du bassin houiller de Klappan et à 5 km à l'est du bassin houiller de Groundhog. La formation de McEvoy se prolonge probablement à au moins 15 km à l'ouest du bassin houiller de Klappan. Les changements de faciès au sein des formations de Currier et de McEvoy, dont d'importantes manifestations de charbon, sont en harmonie avec la variation latérale des systèmes de sédimentation. Des couches attribuées aux formations d'Ashman (Jurassique moyen) et de Tango Creek (Crétacé supérieur) ont également été découvertes dans la région entourant les bassins houillers. Les faciès de la formation d'Ashman sont marins et représentent les plus anciennes roches connues de la région étudiée. Par contre, les faciès de la formation de Tango Creek sont caractéristiques de sédiments de cônes alluviaux et sont probablement les couches les plus récentes de la région.

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INTRODUCTION

The geology of sedimentary rocks of the Bowser Basin exposed in the northern Skeena Mountains remains poorly understood despite reports of significant coal reserves in the area since the early years of this century. Out of these early reports and subsequent reconnaissance geological studies, detailed in Buckham and Latour (1950) and summarized in Bustin and Moffat (1983), came a plethora of general or locally based stratigraphic divisions. However, because of the lack of distinctive marker horizons and the structural complexity of the area, the only widely recognized stratigraphic units have been in the marine rocks that form the base of the exposed sedimentary strata (Tipper and Richards, 1976). Differentiation of the overlying transitional marine and nonmarine sediments into regionally applicable stratigraphic units is a necessary step to improving the understanding of both the coal potential and the geological history of the Bowser Basin.

We recently proposed a formal stratigraphy within the traditional boundaries of the Groundhog coalfield as part of a geological study of the area (Fig. 1; Cookenboo and Bustin, 1989). A primary goal of continuing geological investigation has been to extend this stratigraphy to related rocks in the surrounding area, in order to develop a regionally useful stratigraphy. The traditional boundaries of the Groundhog coalfield have been divided into the Klappan coalfield to the north and the Groundhog coalfield to the south (Koo, 1986), and this division is used in this report.

Reported below are the preliminary results of this study, which involved detailed description and measurement of well exposed sections from a wide area of the northern Bowser Basin (Fig. 2). Included are descriptions of facies changes within stratigraphic units previously described from the Groundhog and Klappan coalfields; descriptions of facies encountered in other stratigraphic units; and revisions to coalfield stratigraphy.

The oldest strata encountered in the study area are assigned to the Ashman Formation, Lower and Middle Jurassic marine strata that are the oldest beds of the Bowser Lake Group (Tipper and Richards, 1976). The Ashman Formation is exposed over a large area of the coalfields and was observed as far south as the central Slamgeesh Range. The Ashman Formation is overlain by transitional marine and nonmarine strata assigned to three formal units: from oldest to youngest the Currier, McEvoy, and Devils Claw formations (Cookenboo and Bustin, 1989). The Currier and McEvoy formations are the main coal-bearing units in the Groundhog and Klappan coalfields.

Sustut Group rocks of Late Cretaceous age are the youngest Mesozoic strata exposed in the study area. Eisbacher (1974a) mapped the Sustut Group east of the Groundhog and

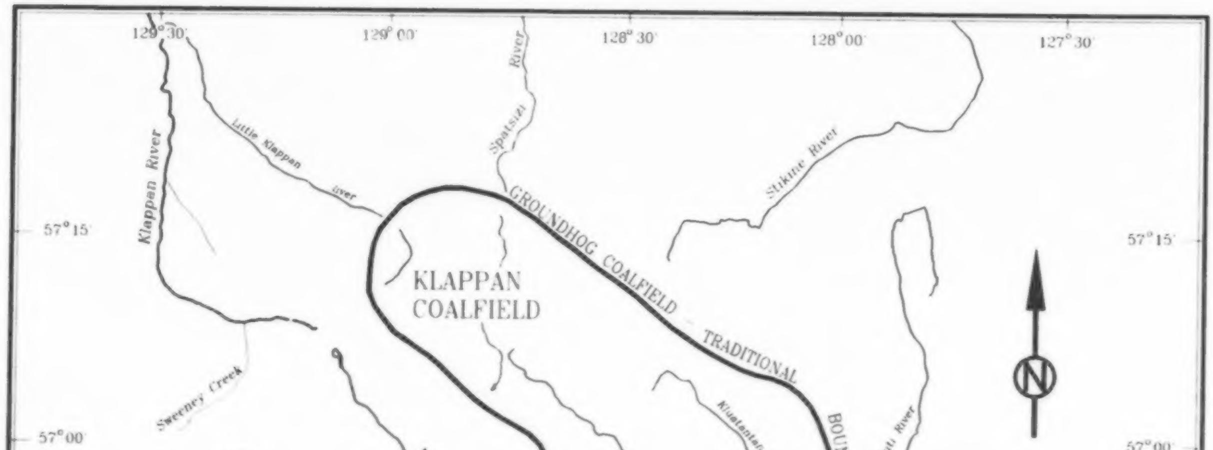
129° 30'
129° 00'
128° 30'
128° 00'
127° 30'
57° 15'
57° 00'
56° 45'
Klappan River
Little Klappan River
Spatsizi River
Stikine River
GROUNDHOG COALFIELD TRADITIONAL BOUNDARY
KLAPPAN COALFIELD
GROUNDHOG COALFIELD
Sweeney Creek
Nass River
Klastantan River
Duti River
Konigus Creek
Currier Creek
Skeena River
Yaza Creek
Mosque River
N
STUDY AREA
B. C.
Location Map
0
15
KILOMETRES

Figure 1. Location map of the study area, showing the Klappan and Groundhog coalfields (after Buckham and Latour, 1950 and Koo, 1986).

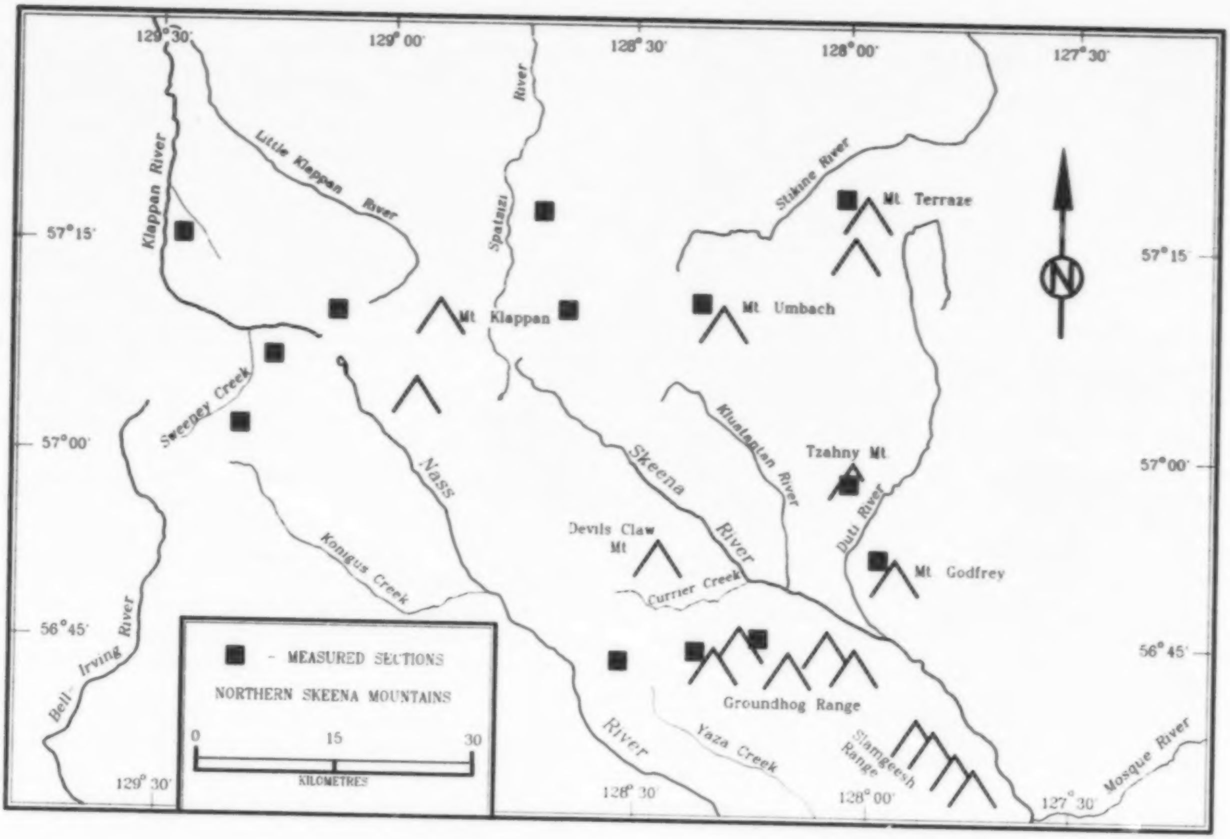
129°30'
129°00'
128°30'
128°00'
127°30'
57°15'
57°00'
56°45'
Klappan River
Little Klappan River
Spatsizi River
Stikine River
Mt. Terraze
Mt Klappan
Mt. Umbach
N
Sweeney Creek
Nass
Skeena River
Klastline River
Tzahny Mt
Duti River
Devils Claw Mt
Mt. Godfrey
Konigus Creek
Currier Creek
Bell-Irving River
■ - MEASURED SECTIONS
NORTHERN SKEENA MOUNTAINS
0
15
30
KILOMETRES
Groundhog Range
River
Yaza Creek
Slamgeesh Range
Mosque River

Figure 2. Locations of sections measured during the 1989 field season.

Klappan coalfields as unconformably overlying Bowser Lake Group sediments. He divided the Sustut Group into an older Tango Creek Formation and younger Brothers Peak Formation. Strata assigned to the Tango Creek Formation have reported ages ranging from mid- Albian to Paleocene (Eisbacher, 1974a; Evenchick, 1986) and are in part contemporaneous with the McEvoy and Devils Claw formations (Cookenboo and Bustin, 1989).

Sections measured this year extend the known area of occurrence of the Currier and McEvoy formations and allow new detailed descriptions of facies of the Ashman and Tango Creek formations. Facies observed for each stratigraphic unit are described below.

ASHMAN FORMATION

Fine grained facies dominate exposures of the Ashman Formation in the study area, as elsewhere in the Bowser Basin. This fine grained facies is dominantly bluish black to dark grey shale and mudstone characterized by thinly spaced cleavage, abundant marine fauna and biogenic structures, and a general absence of plant remains. The mudstones and shales typically coarsen upward in beds up to 35 m thick, with minor thin interbeds (<30 cm) of fine and very fine grained sandstones that weather rusty brown. Yellow-brown-weathering nodules 10-15 cm across are common in mudstones exposed north of Mount Klappan, but are less common in Ashman Formation exposures to the southeast.

Coarser grained facies of thick marine sandstones and conglomerates are common in some sections and constitute a second distinctive lithofacies association. The sandstones and conglomerates, as with the mudstones and shales of the fine grained facies, commonly exhibit coarsening upward trends and are rich in marine fauna. Sandstones are fine to very fine grained and weather medium to light grey with minor rusty zones and occur in beds 10-20 m thick. Several sandstones in the upper Ashman Formation contain orange-brown-weathering shell lags (in some cases mixed with well sorted, small chert pebbles) up to 1 m thick (Fig. 3) that are sufficiently distinctive and laterally extensive to serve as good local marker beds. Conglomerate clasts, well rounded and almost entirely composed of chert, typically are 1-3 cm across. Conglomerate beds are up to 40 m thick, but more commonly 10-20 cm thick.

The coarser grained facies is best developed in the northeast part of the area. This facies is interbedded with variable proportions of the fine grained facies, suggesting it too was deposited in a marine environment. This coarse grained lithofacies occurs most abundantly in the upper 150-300 m of the Ashman Formation, just below the transitional marine and nonmarine beds of the Currier Formation, suggesting

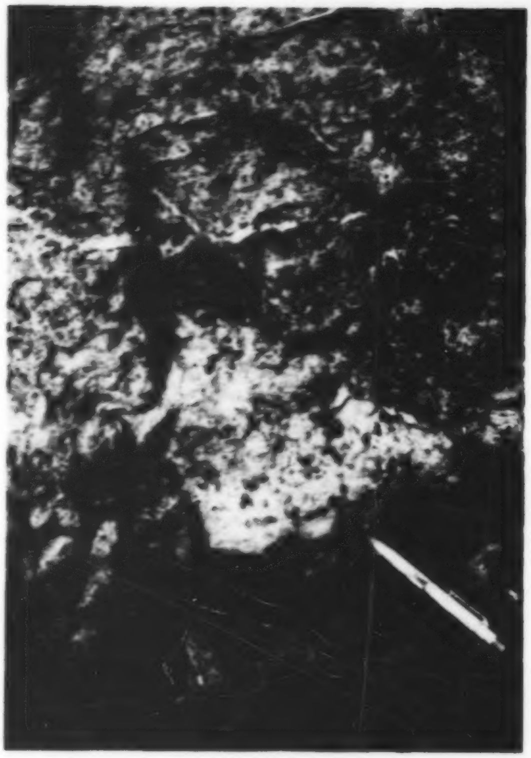

Figure 3. Distinctive bivalve shell bed from a yellow-brown weathered sandstone in the Ashman Formation.

shoaling up at the top of the Ashman Formation. A third facies, characterized by coarse grained debris flows, occurs in stratigraphically lower Ashman rocks exposed in the Slamgeesh Mountains. This facies may be related to coarse grained turbidite facies reported by Eisbacher (1974b), but it has not been encountered elsewhere within the study area and will not be described in more detail here. However, debris flows and turbidite deposits in older Ashman deposits overlain by shallow marine deposits (which are in turn overlain by marginal marine and terrestrial deposits of the Currier Formation) suggests that the Ashman Formation may represent a period of shelf construction on the western margin of the Canadian Cordillera.

CURRIER FORMATION

The Currier Formation was originally named for coal-bearing strata exposed in the vicinity of Currier Creek in the southern part of the Groundhog coalfield (Bustin and Moffat, 1983). The name was formalized by Cookenboo and Bustin (1989) to include similar strata exposed in the Klappan coalfield. Fieldwork during 1989 extends the Currier Formation northwest of the Klappan coalfield and east of the Groundhog coalfield. The Currier Formation was not seen south of the Groundhog Range. The overall thickness of the unit has also been extended, with the basal formation contact redefined as the top of the Ashman Formation.

Because of poor exposure of the basal contact of the Currier Formation in the Klappan and Groundhog coalfields, the relation of the Currier to the marine Ashman Formation was uncertain when the stratigraphy for the coalfields was proposed. A transitional unit between the marine shales of the Ashman Formation and the marine and nonmarine strata of the Currier Formation was mapped by Moffat (1985) in the Klappan coalfield, but was not recognized in the Groundhog coalfield (Bustin and Moffat, 1983). The upward transition from marine shales and sandstones of the Ashman Formation to transitional marine and nonmarine strata is well exposed in two sections examined this year (Mount Umbach and Mount Godfrey; Fig. 2), allowing revision and clarification of the basal contact of the Currier Formation. The transition is recognized by the first appearance of coal and leaf fossils, and corresponds to a general increase in plant remains (including tree trunks up to 20 m long exposed on sandstone surfaces on Mount Godfrey; Fig. 4) and decrease in marine fauna.

The transition from the fully marine Ashman Formation to marginal marine coal bearing strata is correlatable from Mount Godfrey to Mount Umbach, suggesting that this change marks the base of the Currier Formation. The informal Jackson unit, used by previous workers, is abandoned: the lower, marine part of the Jackson is included in the Ashman Formation and the upper, transitional marine to nonmarine part is included in the Currier Formation. This revision

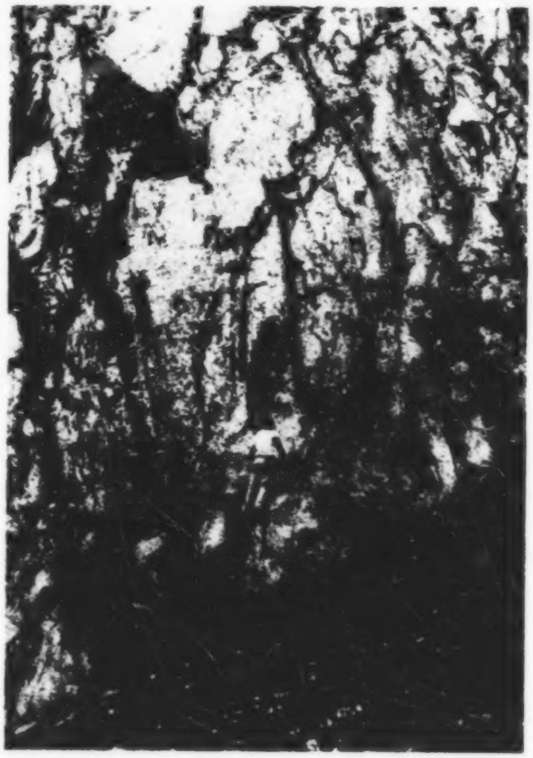

Figure 4. Preserved tree casts on exposed sandstone surface near the base of the Currier Formation on Mt. Godfrey. The best preserved trunk is nearly 6 m long and 1 m across diameter (directly above geologist). Another even larger tree trunk, roughly parallel to the first, is visible on the left side of the photo.

of the stratigraphy increases the overall thickness of the Currier Formation near the Klappan coalfield to 1000 m or more, similar to estimates made by J. Innis and E. Swanbergson (personal communication, 1989). The apparently greater thickness of Currier Formation in the north may be due to depositional variation, or may be an angular expression of the presumed unconformity that separates the Currier from the overlying McEvoy Formation (Cookenboo and Bustin, 1989).

Sections measured this year showed coal development outside the Groundhog and Klappan coalfields, with the best development occurring in the lower half of the Currier Formation. The thickest seams, one 8 m and the other 10 m thick, are exposed on a northwest trending ridge east of the Klappan river (Fig. 2). These two seams are both partly covered and may not be continuous, but the only rock exposed in both locations is coal. Good coal development, including several seams in 3-5 m thick, was also found near Mt. Tzahny, east of the Groundhog coalfield.

McEVOY AND DEVILS CLAW FORMATION

About 1500 m composite thickness of strata correlative to the McEvoy Formation crop out in two sections southeast of Sweeney Creek, thus extending the McEvoy Formation 15 km farther west than previously reported. The rocks examined east of Sweeney Creek are generally a finer grained facies, with fewer massive conglomerates and better development of coal than those in the type area to the east of the Nass River (Cookenboo and Bustin, 1989). Plant fossils are abundant in the McEvoy Formation exposures, as they are in the Currier Formation, but unlike the Ashman Formation, marine fauna are absent. Distinguishing these facies as McEvoy rather than Currier Formation in the field rests on subtle lithological differences. The most recognizable differences are a dominance of siltstone over shale, more abundant conglomerates, and thinner coals in the McEvoy Formation compared to the Currier Formation. Correlation of the Sweeney Creek exposures with the McEvoy rather than the Currier Formation is supported by vitrinite reflectance values for coals in the sections, which are significantly lower (2.2 % compared to 3.0-5.0 % or greater) than typical values reported from the Klappan and Groundhog coalfields to the east (Cookenboo and Bustin, 1990). The lower values for the Sweeney Creek coals is consistent with stratigraphically higher position, and therefore lower paleotemperatures, than the Groundhog and Klappan coals.

SUSTUT GROUP

Rocks tentatively assigned to the Sustut Group occur in a section more than 600 m thick on the northwest flank of Mount Terraze. These rocks were previously mapped as Jurassic Bowser Assemblage by Eisbacher (1974a).

Facies exposed on Mount Terraze are characterized by thick coarsening upward units grading from shales, siltstones and wackes at the base to arenites, pebbly sandstones and conglomerates at the top. These coarsening upward units themselves change upward, and can be divided, for descriptive purposes, into a lower and upper facies. The lower facies is composed of grey to tan-weathering beds of siltstones and wackes coarsening up to pebbly sandstones and pebble conglomerates (clasts <2 cm) with only rare and thin (<1 m) shales. The upper facies is characterized by recessive beds of thick carbonaceous dark grey to black shales that coarsen up to mudstone and are capped by massive rusty and grey-weathering cliff-forming pebble-cobble conglomerates. Coal seams up to 2 m thick occur in carbonaceous shale beds within these higher coarsening upward units. Thickness of the coarsening upward units range from 20-50 m in the lower facies and up to 65 m in the upper facies.

Sedimentological characteristics, including the poorly sorted nature of the wackes and siltstones, and the repeated and regular stacking of the coarsening upward units suggest that Mount Terraze facies were deposited in an alluvial fan system. Supporting an alluvial interpretation is the lack of marine macrofauna in the section. The increasingly coarse conglomerates of the upper facies suggest that the alluvial fan system was prograding throughout its existence. The alluvial nature of the Mount Terraze facies differs from the marine and fluvial-deltaic facies Bowser Lake Group and younger rocks exposed to the south and east, but is consistent with those of the Sustut Group. Until paleontological ages are forthcoming, the possibility that Mount Terraze strata are an updip equivalent to Bowser Lake Group or the McEvoy and Devils Claw formations remains unproven. A younger age than the Currier or McEvoy formations is, however, suggested for the strata by the low measured average vitrinite reflectance values (1.01 and 1.07 %) from coals collected in the upper part of the section. Such values are equivalent to high volatile bituminous A, significantly lower than the values of anthracite rank previously reported for the Bowser Basin (Bustin, 1984), but consistent with these rocks being younger and exposed to lower temperatures during their history.

The Mount Terraze section is characterized by gently folded and inclined beds, differing markedly from the tight folds in Bowser Lake Group exposed nearby. The rocks on Mt. Terraze may be more closely related to the ridge to the southeast on which Eisbacher mapped Sustut Group rocks in angular unconformable relation above tightly folded rocks equivalent to the Bowser Lake Group.

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